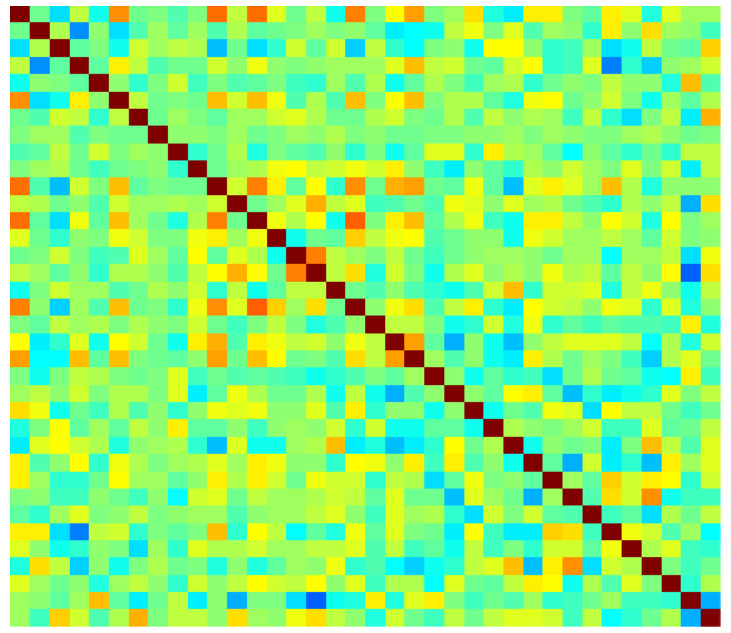
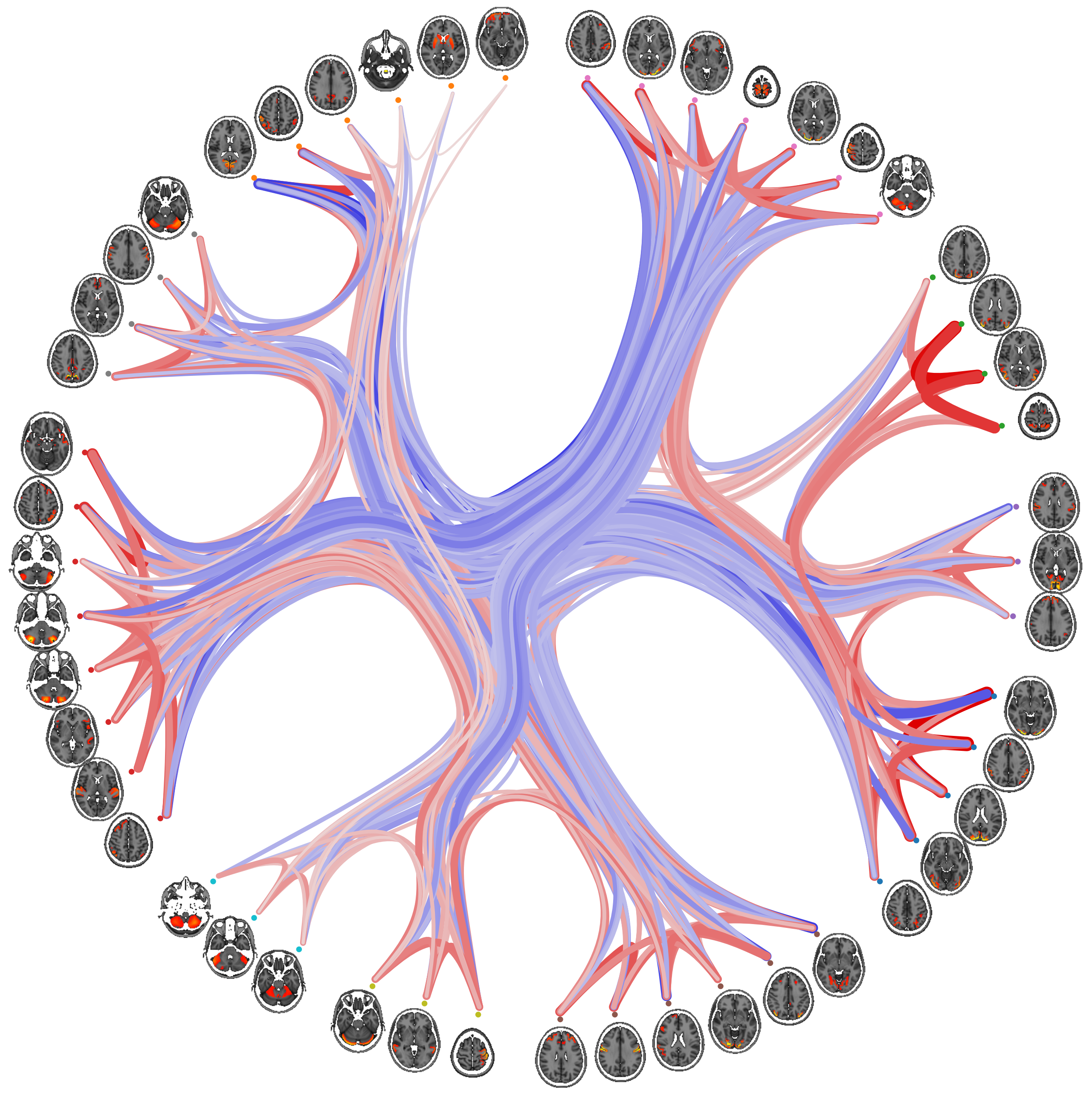
Network modelling analysis

脑网络分析

- Resting state data characteristics 静息态数据特征
- Preprocessing 预处理
- Network modelling analysis 网络建模
- Methods comparisons and considerations 方法比较和注意事项





中文翻译：李宏 孔亚卓

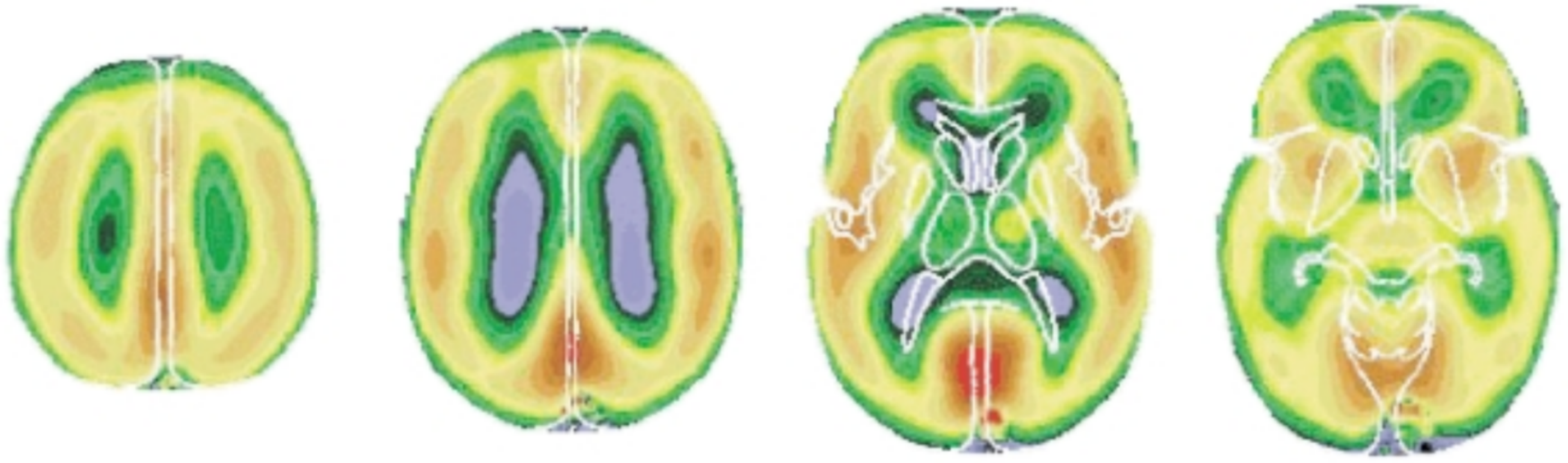
Energy consumption in the brain
大脑的能量消耗

- Brain < 2% body weight but consumes ~20% of total energy
  大脑重量约占身体的<2%,但却消耗约20%的总能量

- estimated 60-80% of this energy used to support communication between cells
  约60-80%的能量用于细胞间的交流

- task-evoked activity accounts for ~1%
  任务诱发的脑活动约占1%

Oxygen consumption 耗氧量



Raichle et al (2006), Gusnard et al (2001)

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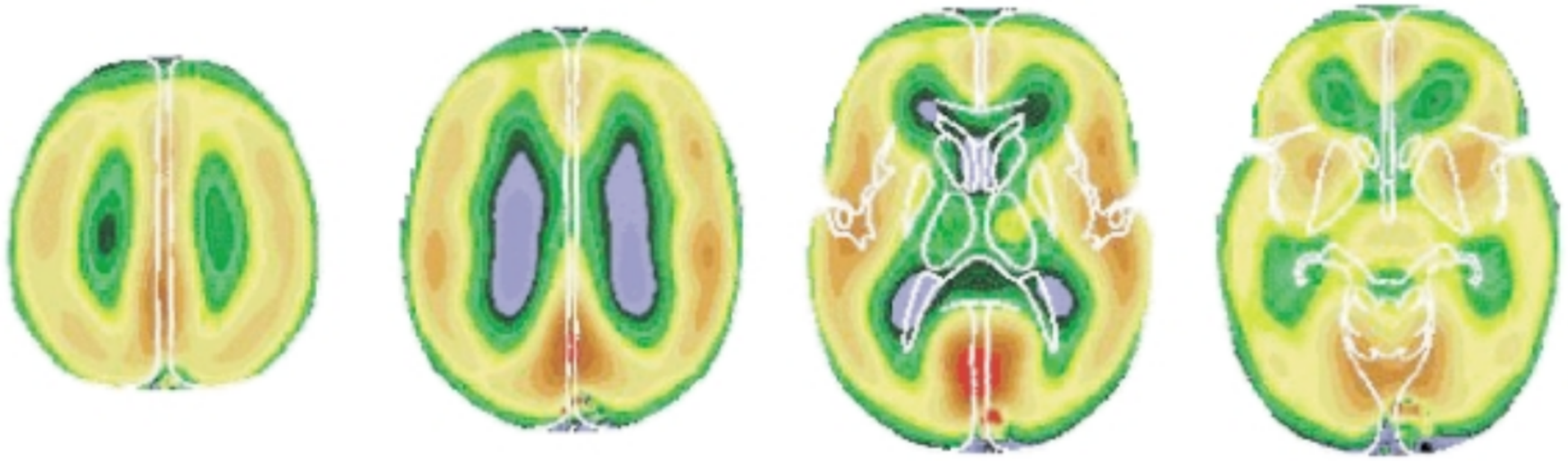
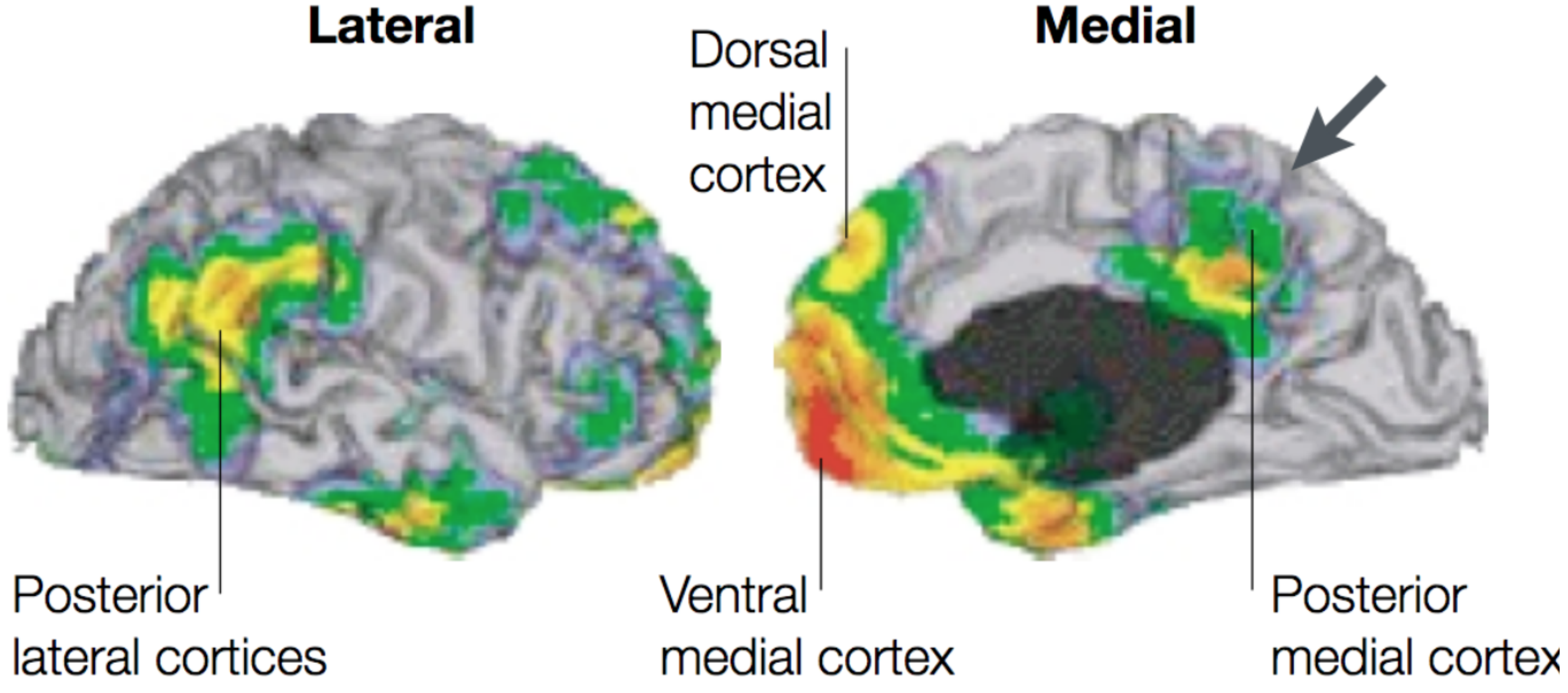


Decreased activity during tasks (PET)
执行任务时脑活动下降



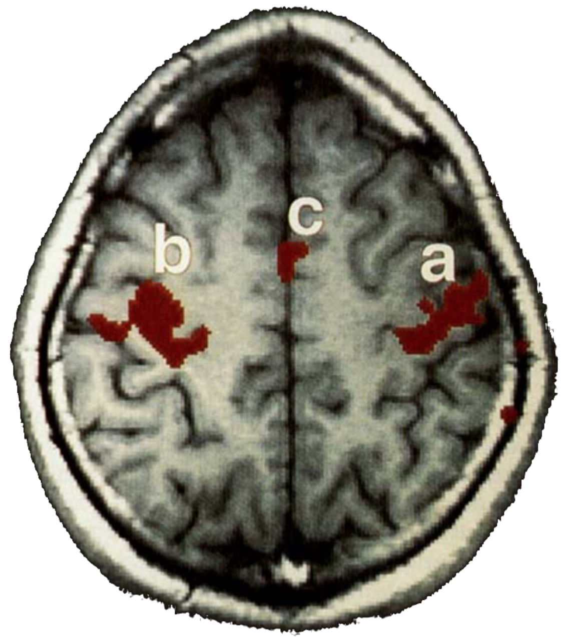
Raichle et al (2006), Gusnard et al (2001)

Why study the brain at rest?
为什么研究大脑的静息态

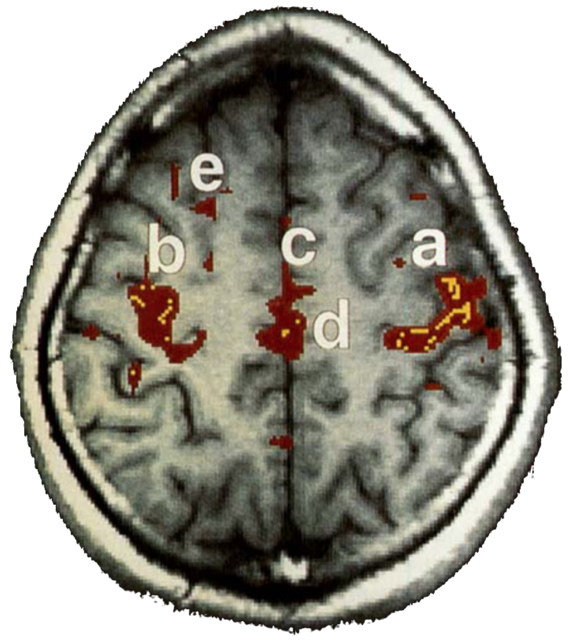
- Localisation versus connectivity 定位与连接

- Understand the inherent functional organisation of the brain 了解大脑固有的功能活动

Finger tapping 手指活动



Rest 静息态



Biswal et al (1995), Sheline et al (2010)

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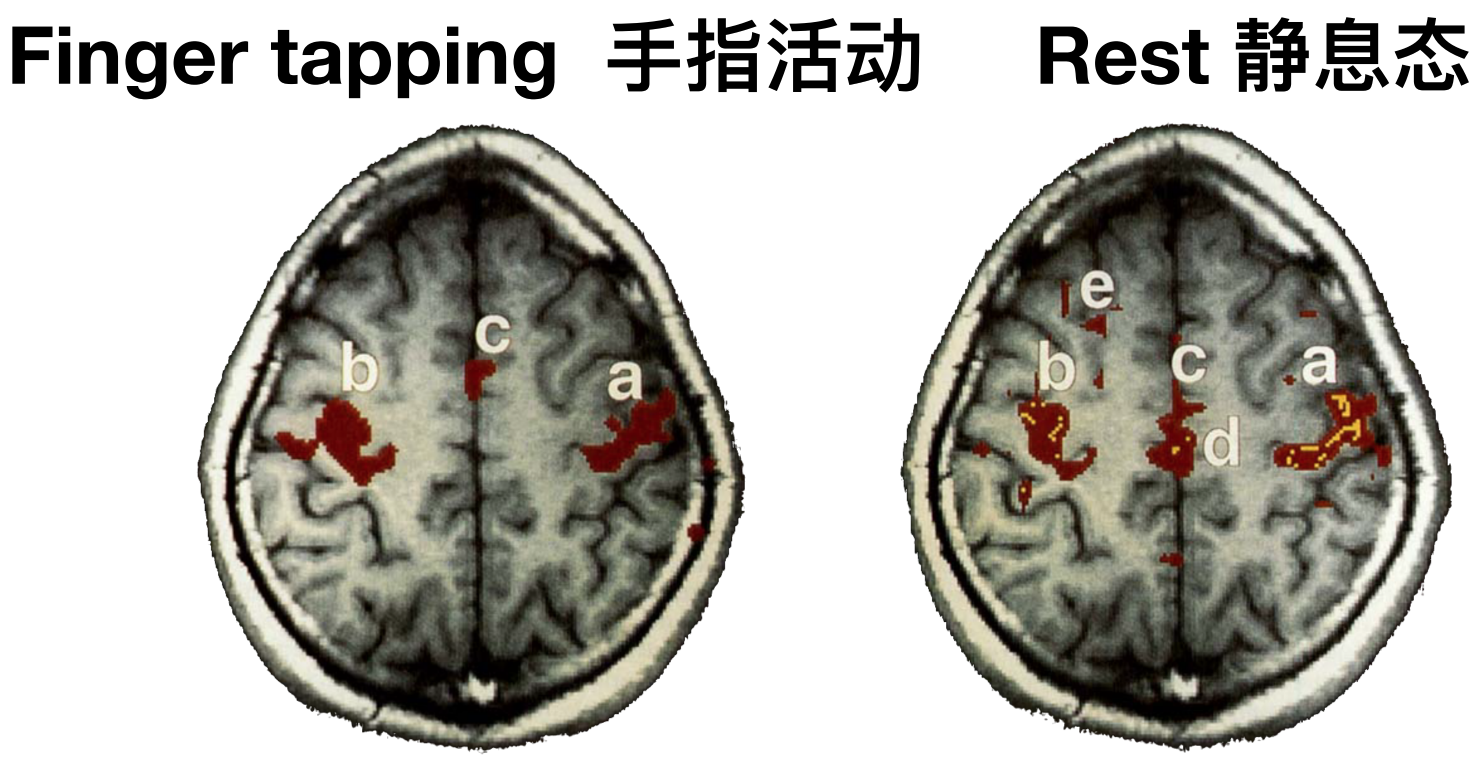
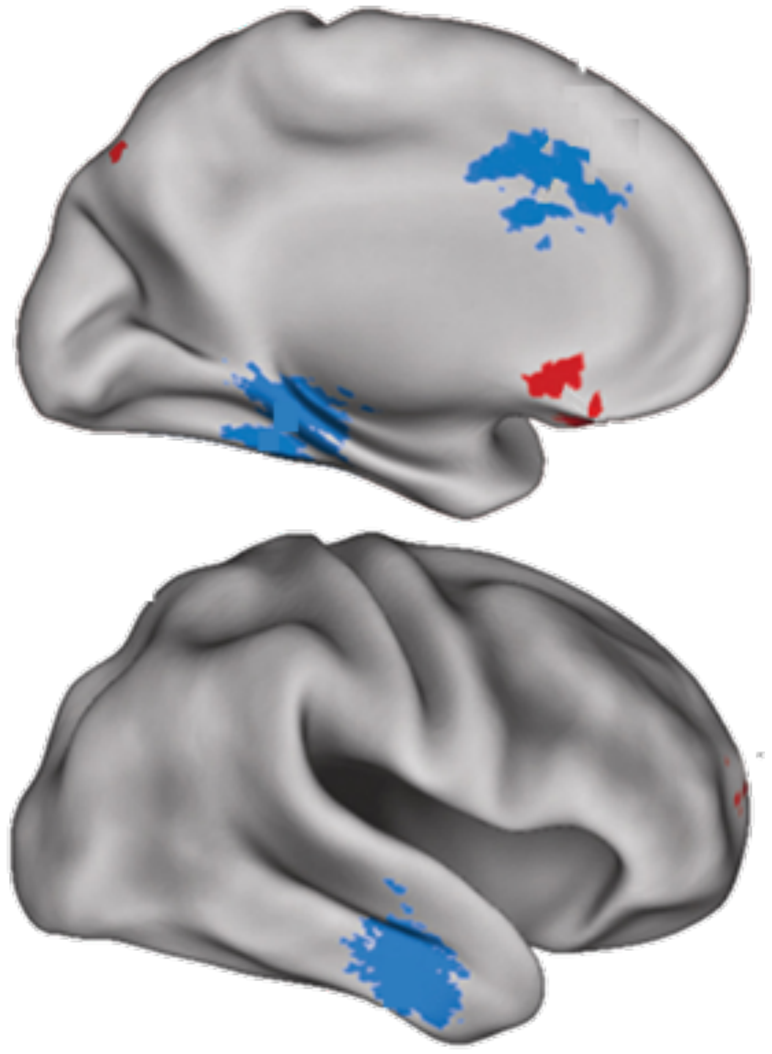
- Clinical/ cognitive biomarker 临床/认知标记





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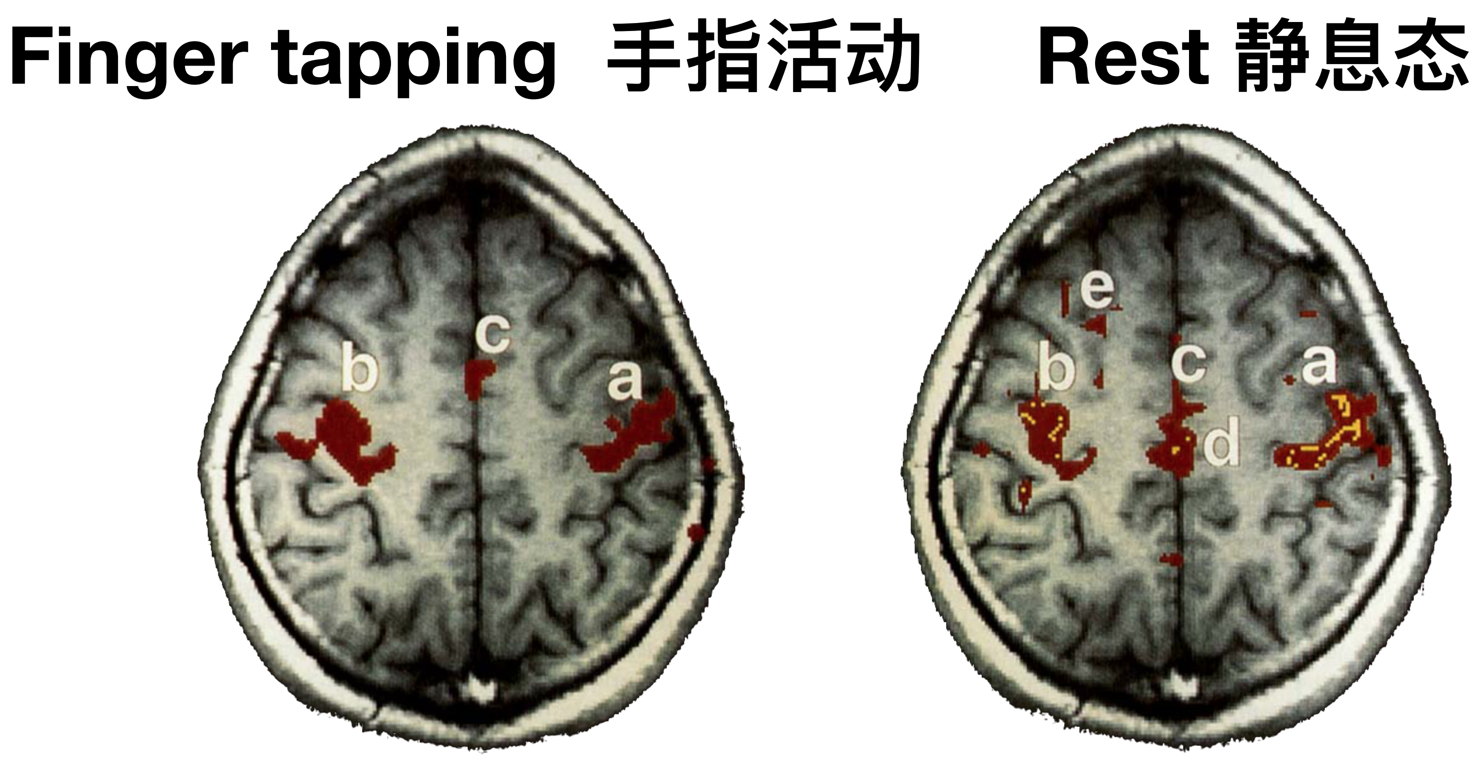
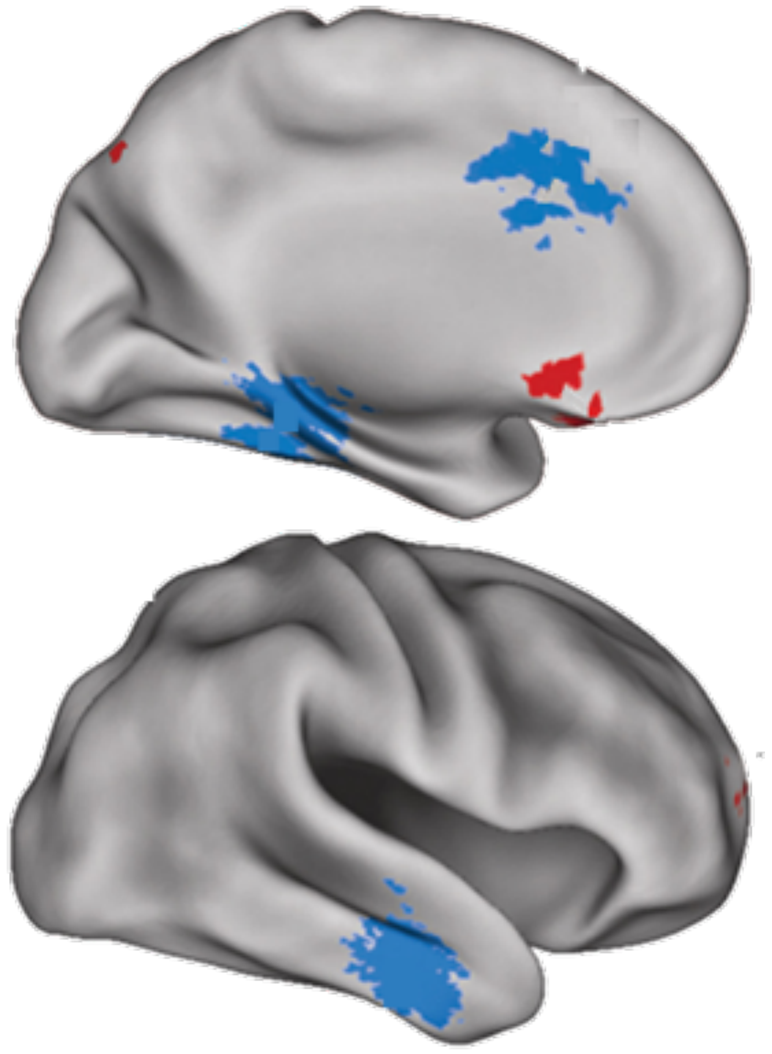
- Understand the inherent functional organisation of the brain 了解大脑固有的功能活动
- Clinical/ cognitive biomarker 临床/认知标记
- Pragmatic benefits: can be done in any population, with relatively little setup and expertise required 实用的优点：可以在任何人群中完成，只需要相对较少的设置和专业知识





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Resting state data analysis
静息态数据分析

- Many different methods available for analysis
  可用许多不同的分析方法
- All have one assumption in common: 它们共同的假设:
- i.e.Definition of functional connectivity is based on a statistical dependency between time series
  功能连接的定义是基于时间序列之间的统计依赖性
- Differences between methods lie in the way these similarities are estimated and/or represented

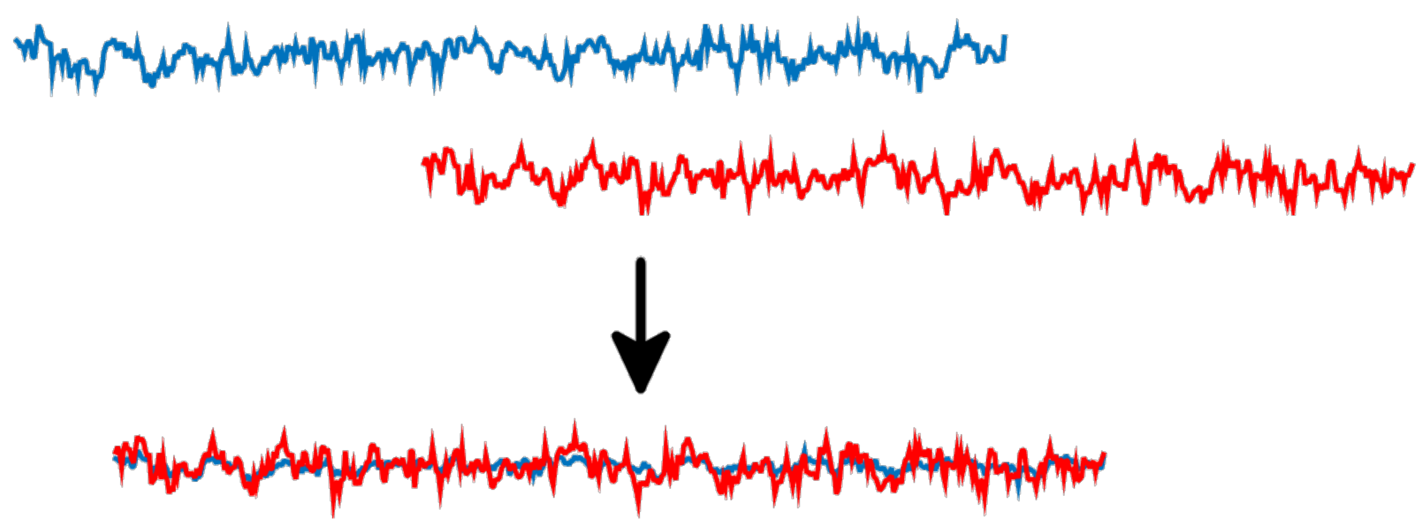
  方法之间的差异在于估计和/或表示这些相似性的方式

If two brain regions show similarities in their BOLD timeseries, they are functionally connected

如果两个大脑区域在其BOLD时间序列中显示出相似性，则它们在功能上是相互关联的

Types of connectivity
连接的类型

- Functional connectivity 功能连接
  - Statistical dependency 统计依赖性
- Effective connectivity 有效连接
  - Directional influence 方向的影响
- Anatomical (structural) connectivity 结构连接
  - Presence of a white matter tract 白质纤维束



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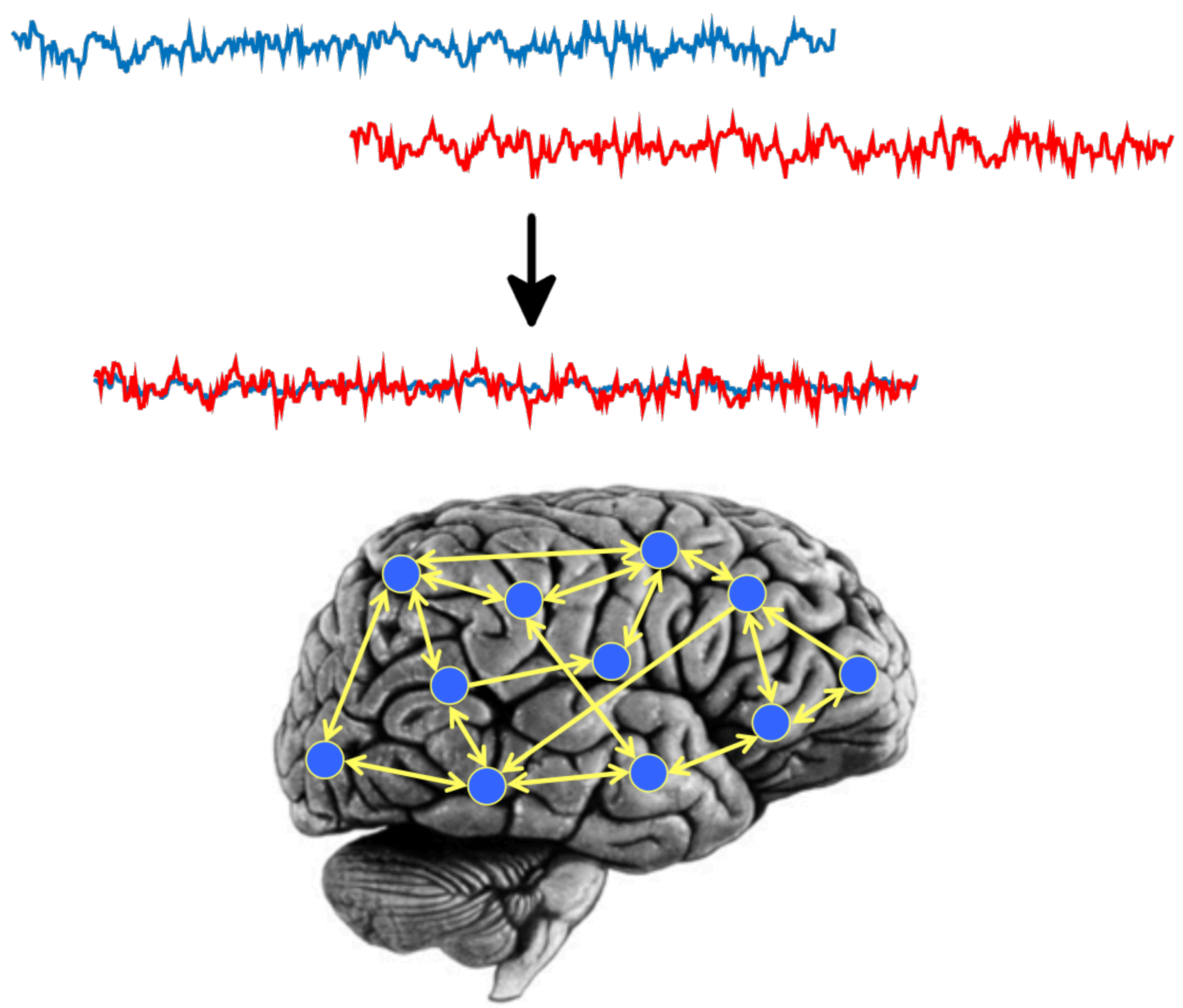

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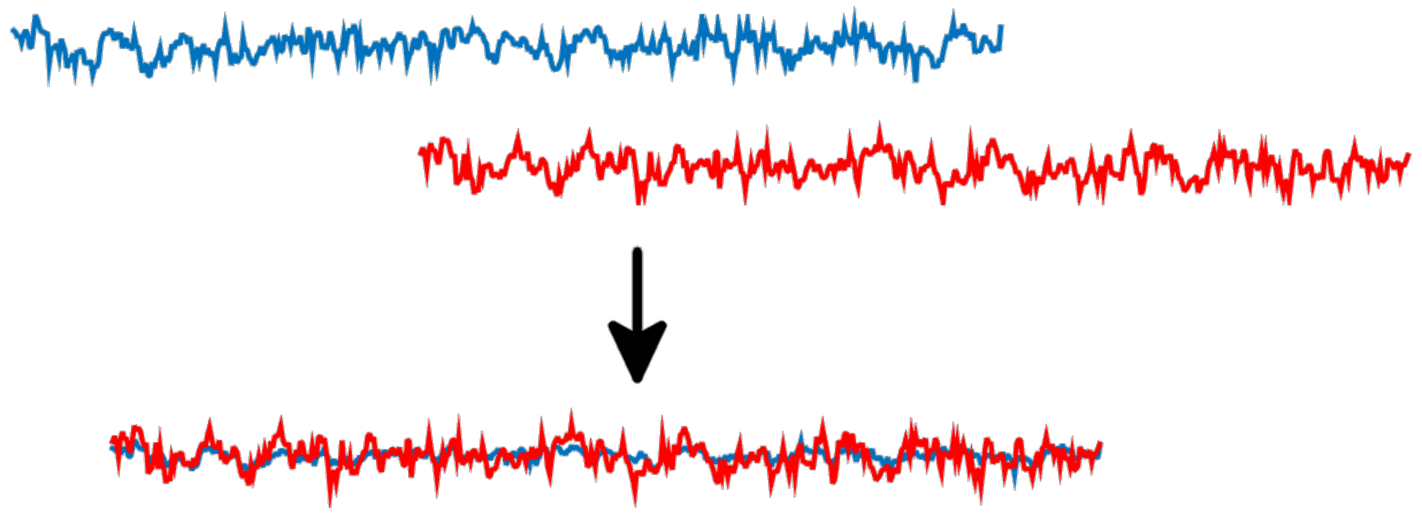
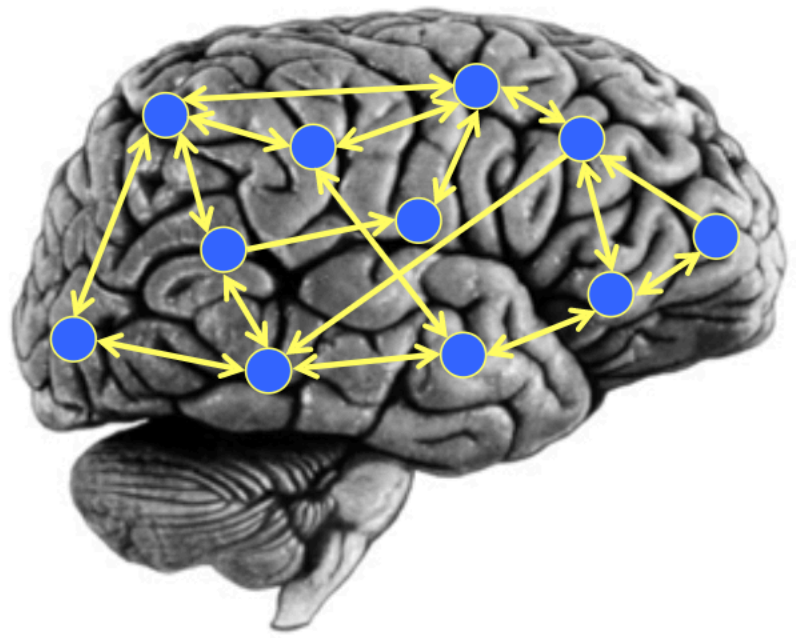
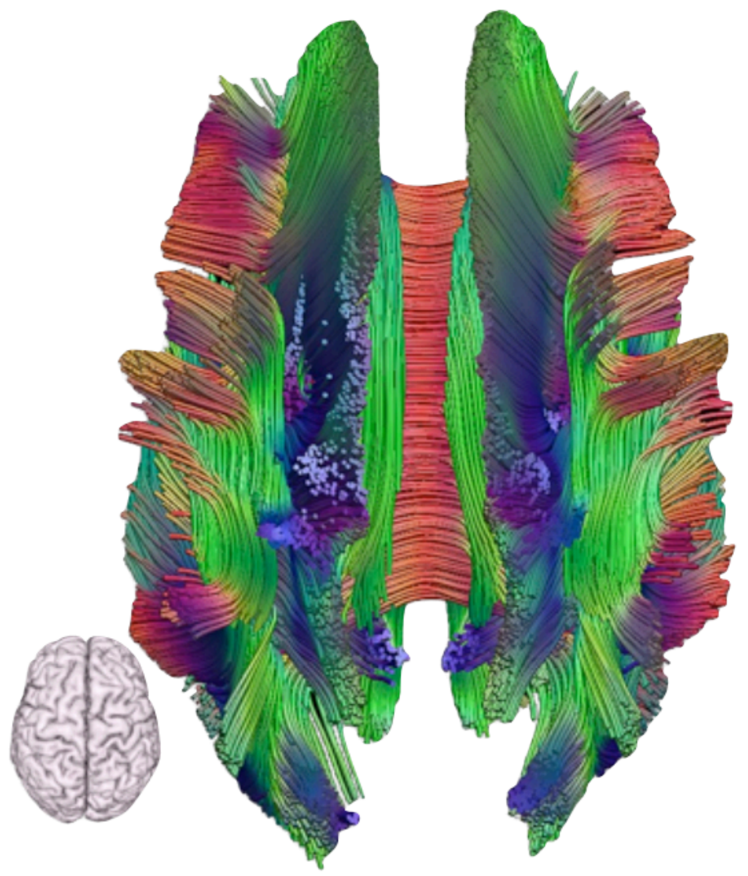


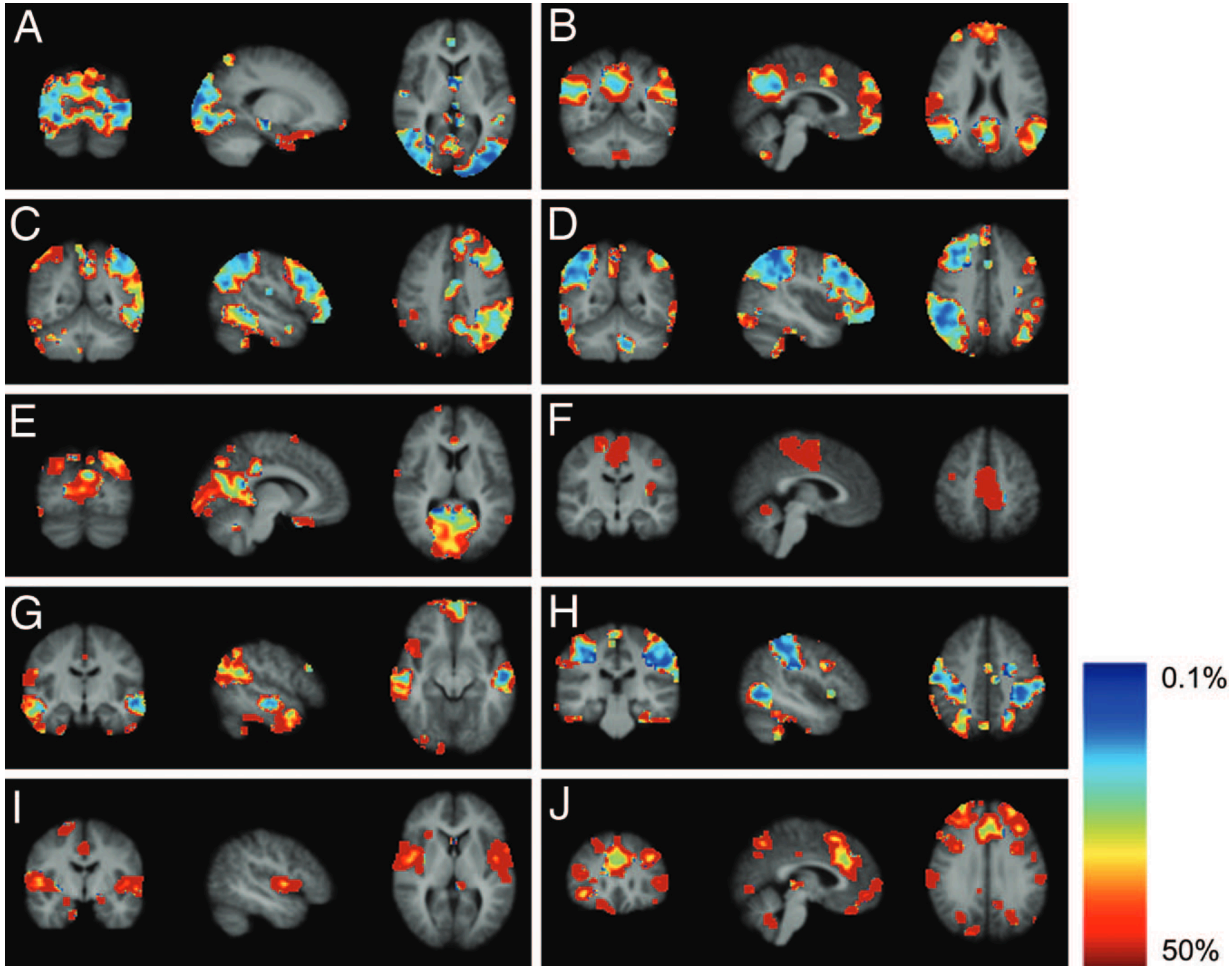




Data characteristics
数据特征

Replicable networks
可重复的网络

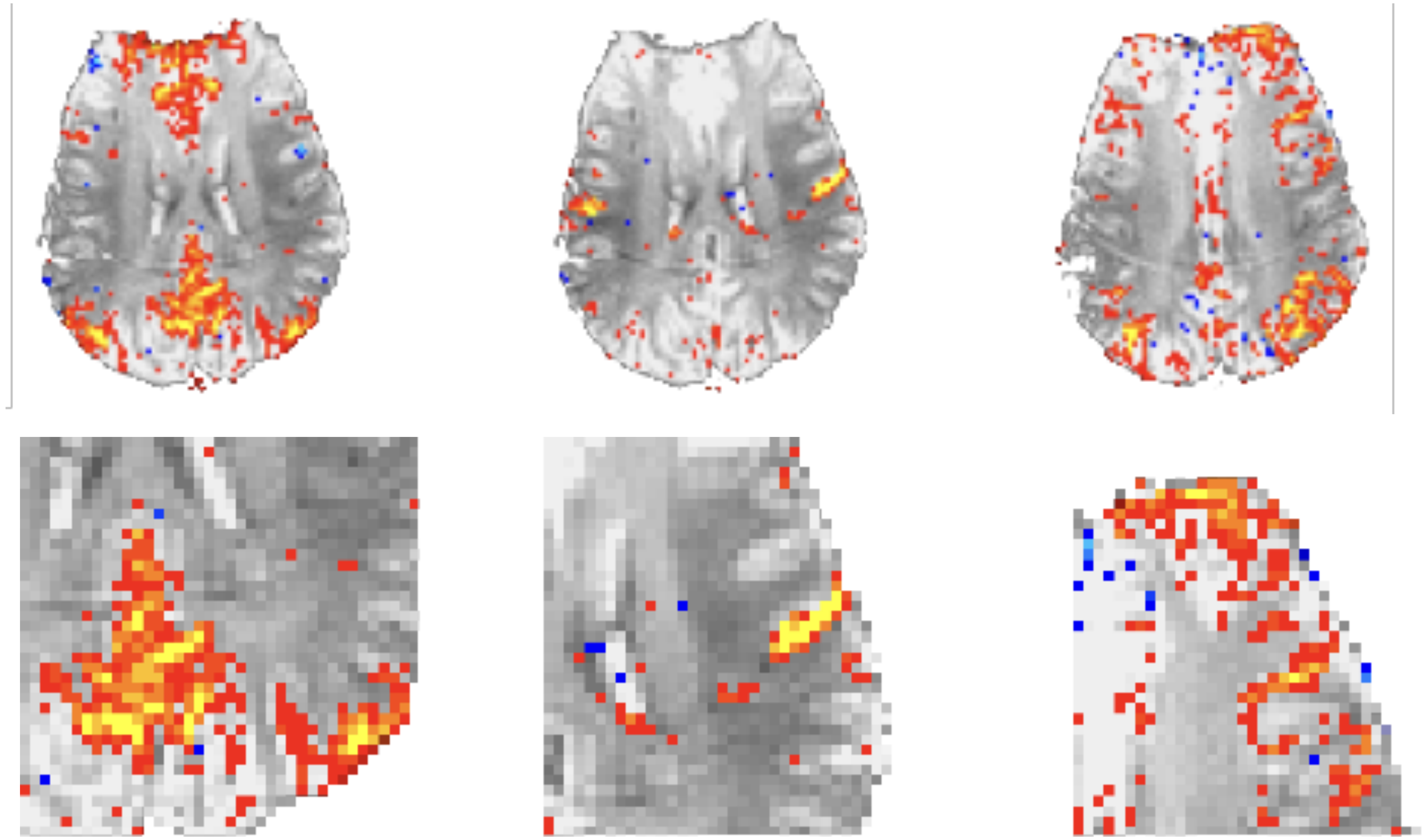
Large-scale inherent organisation is reproducibly found across studies and approaches
多种研究和方法可重复地发现脑内存在大规模的固有组织



Damoiseaux et al (2006)

Grey matter networks
灰质网络

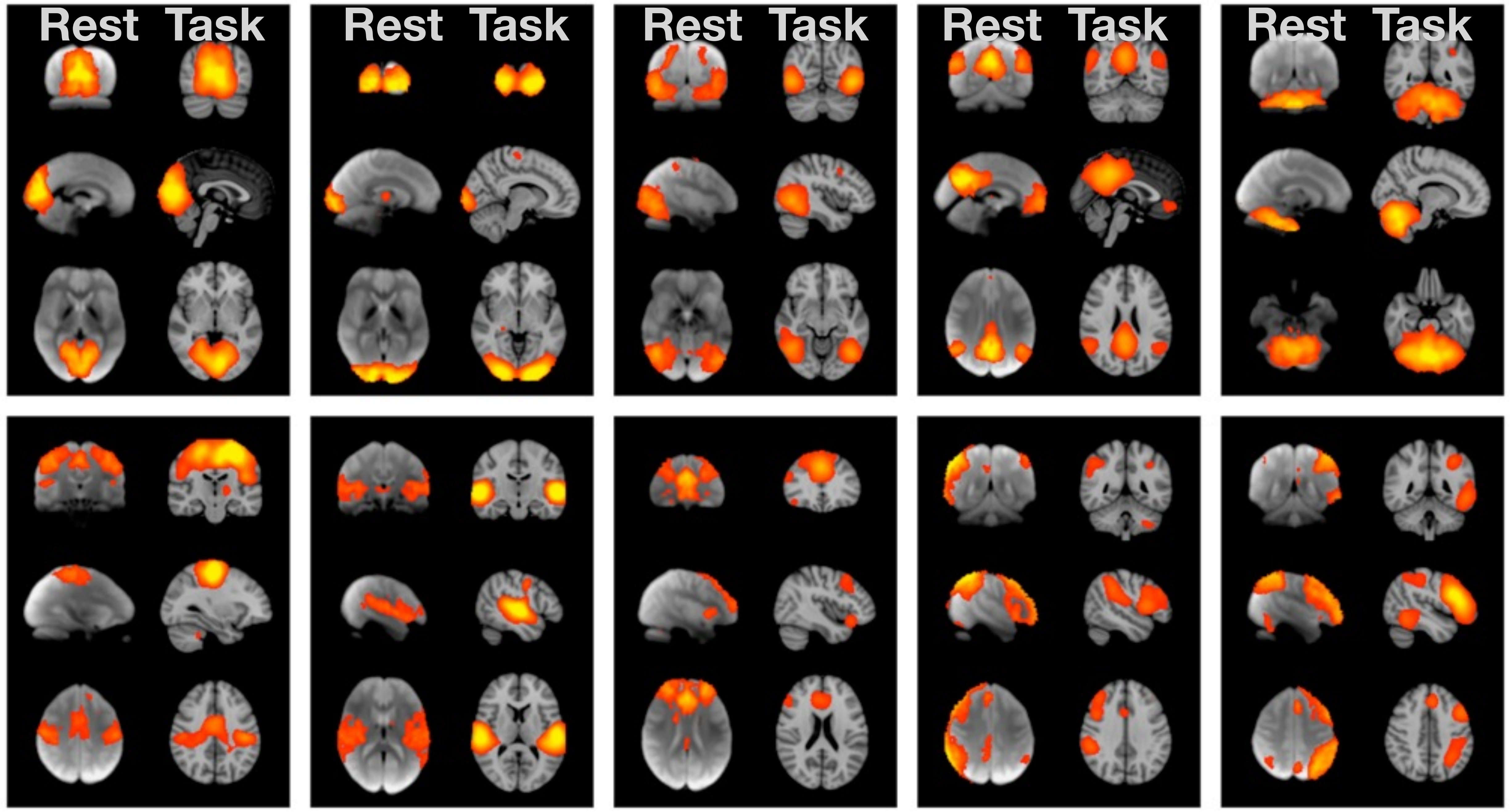
Resting state network structure is localised in grey matter
静息态网络结构位于灰质内

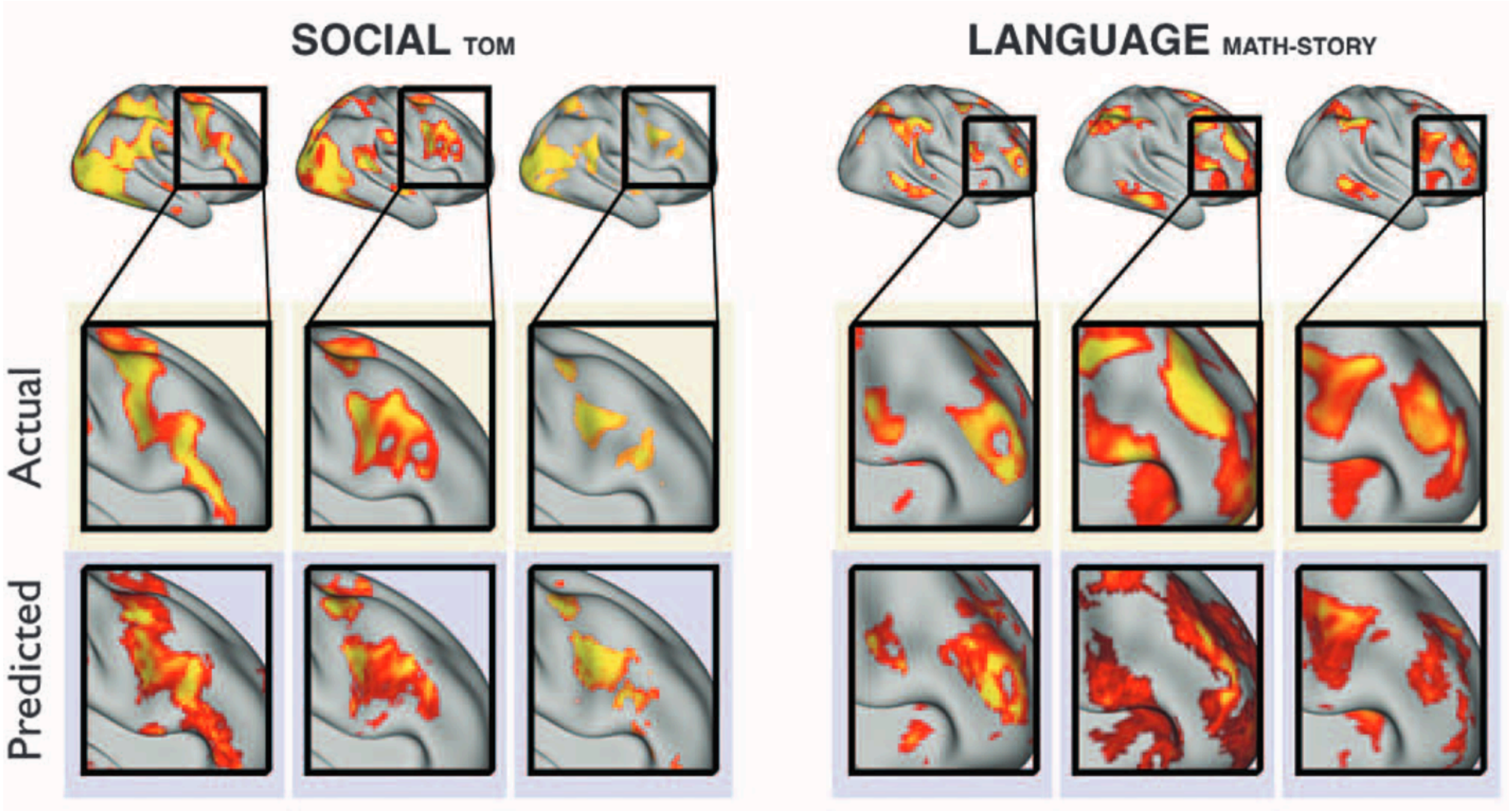


Relationship to task
与任务的关系

Resting state networks are similar to task activation patterns at group and single subject level

静息态网络类似于组和单个被试的任务激活模式

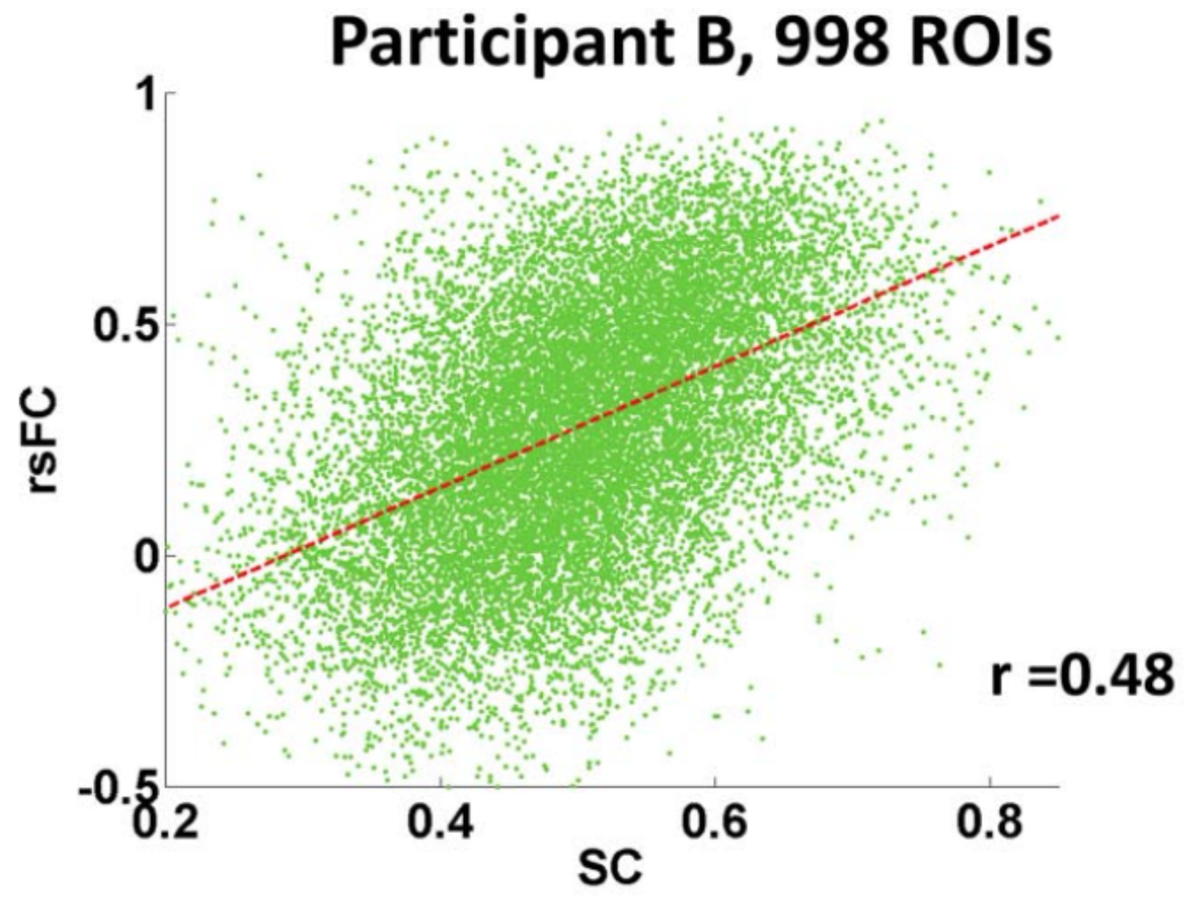


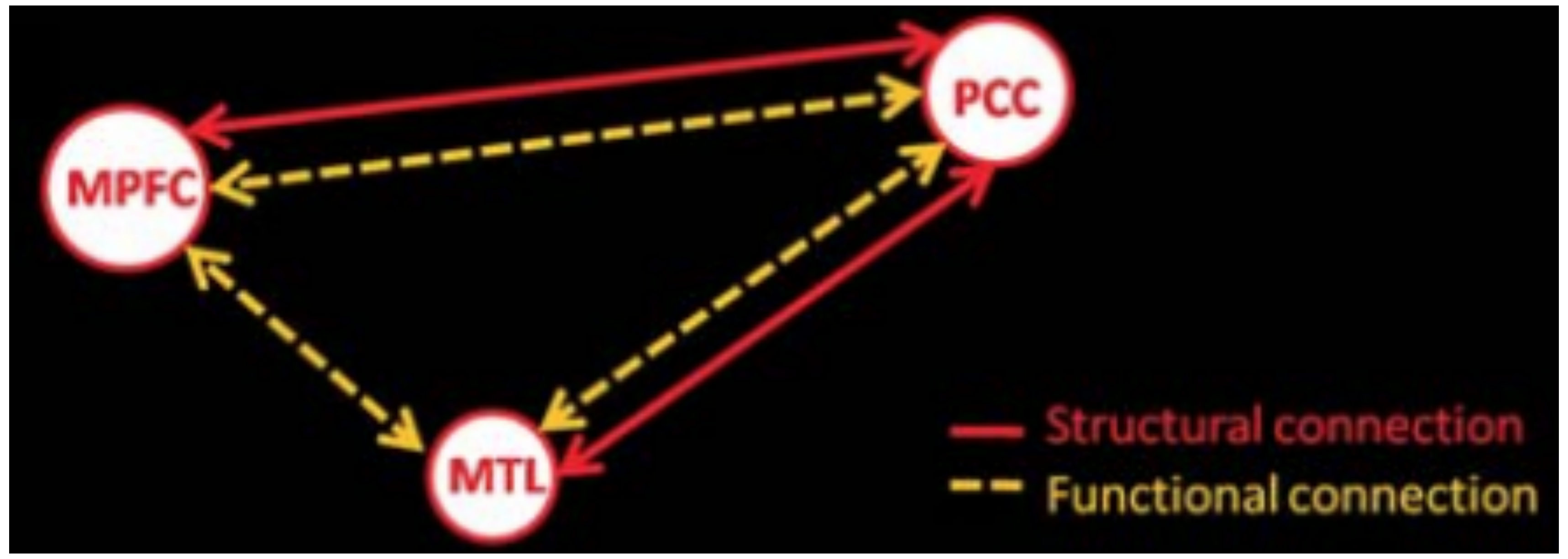


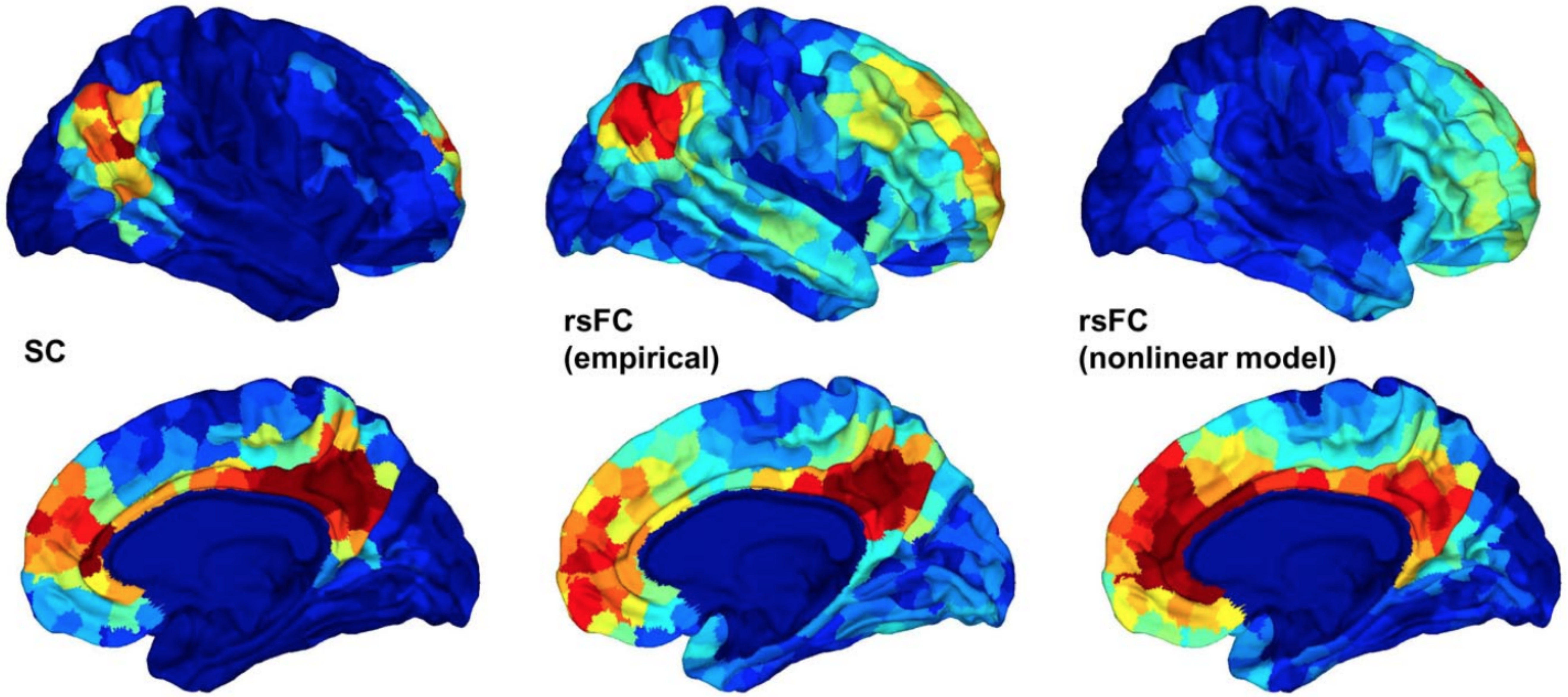
Smith et al (2009), Tavor et al (2016)

Functional vs structural connectivity
功能和结构连接

Functional connectivity is related to structural connectivity
功能连接与结构连接有关



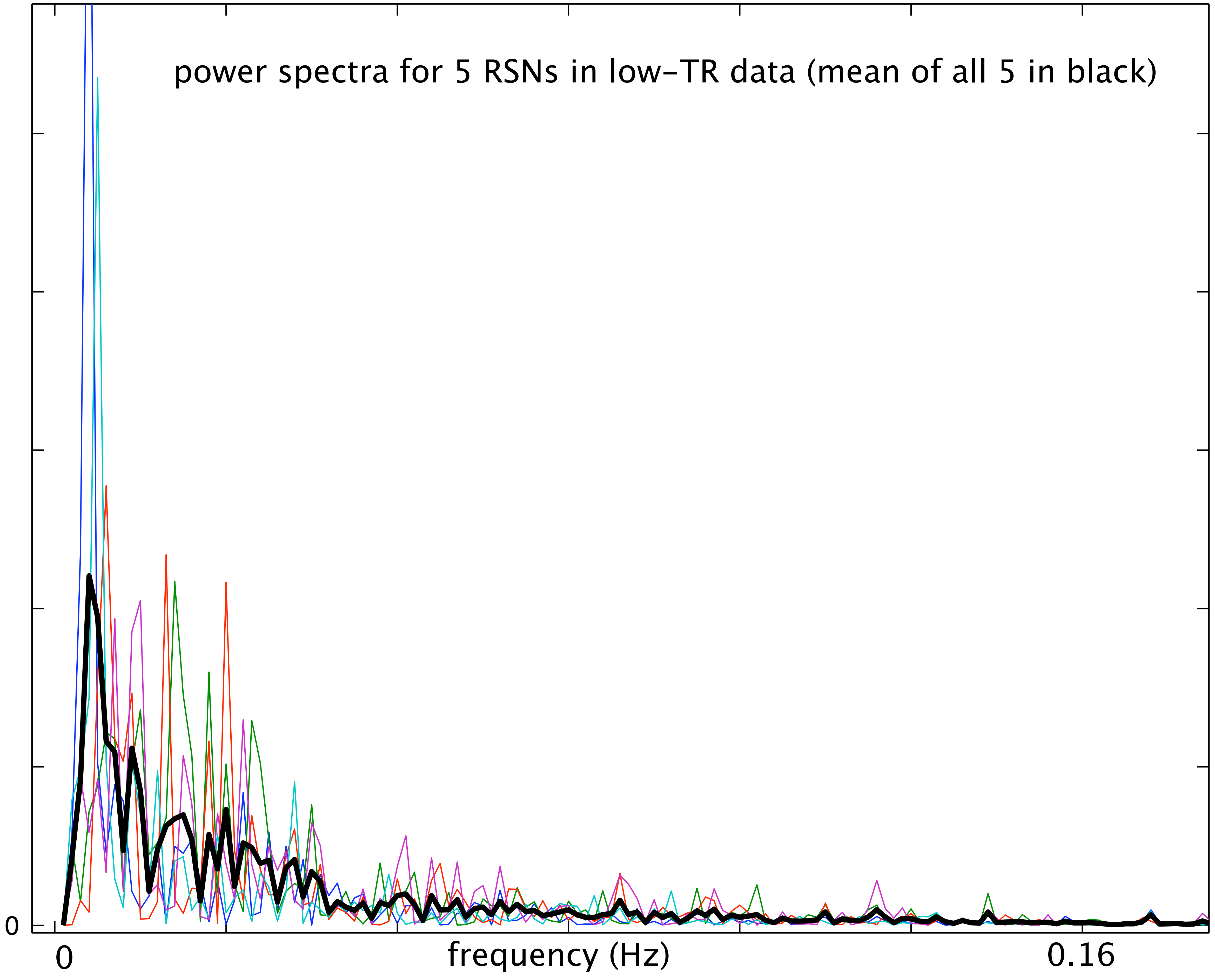


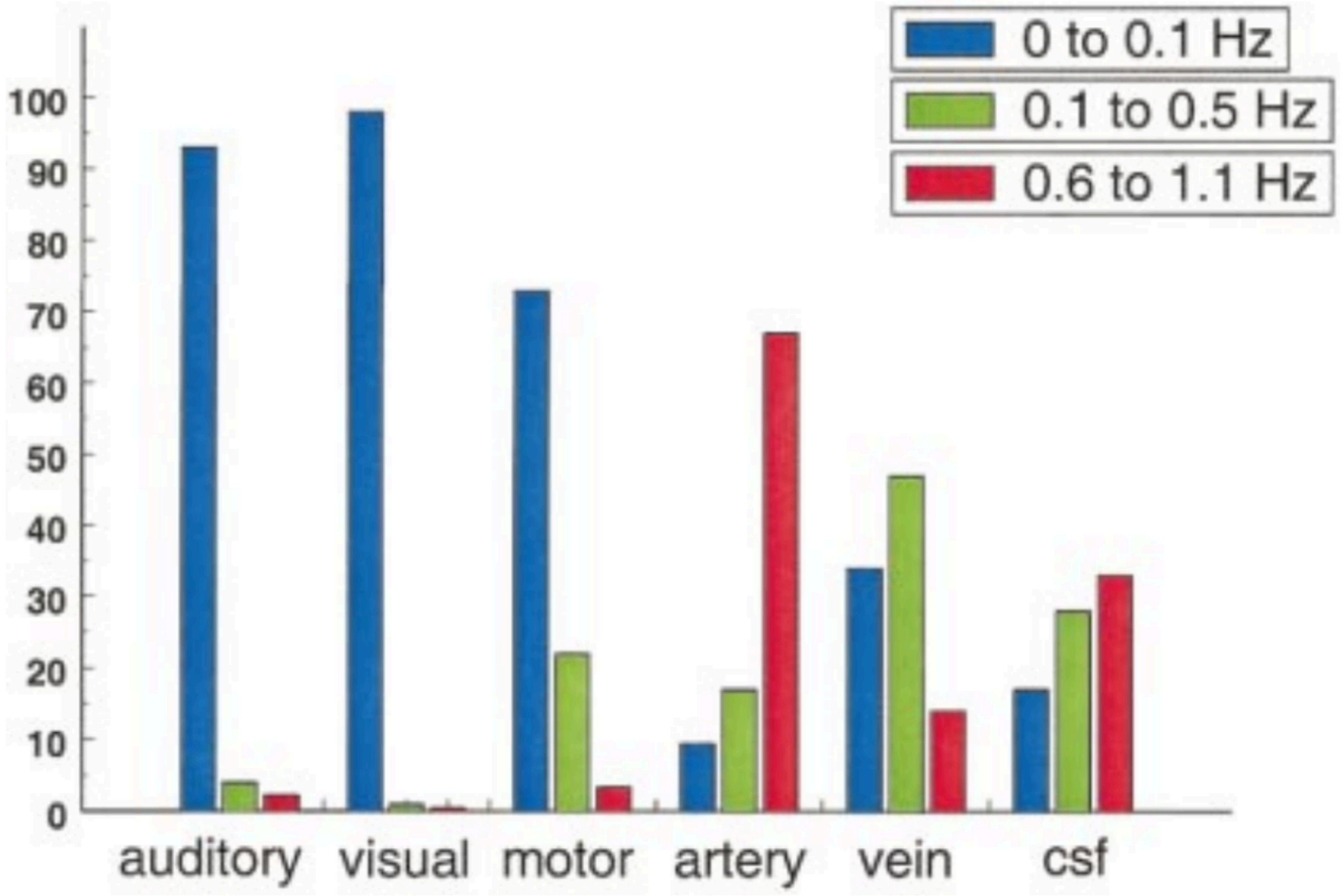


Honey et al (2009), Damoiseaux & Greicius (2009)

Low frequency fluctuations?

低频波动振幅?





Cordes et al (2001)

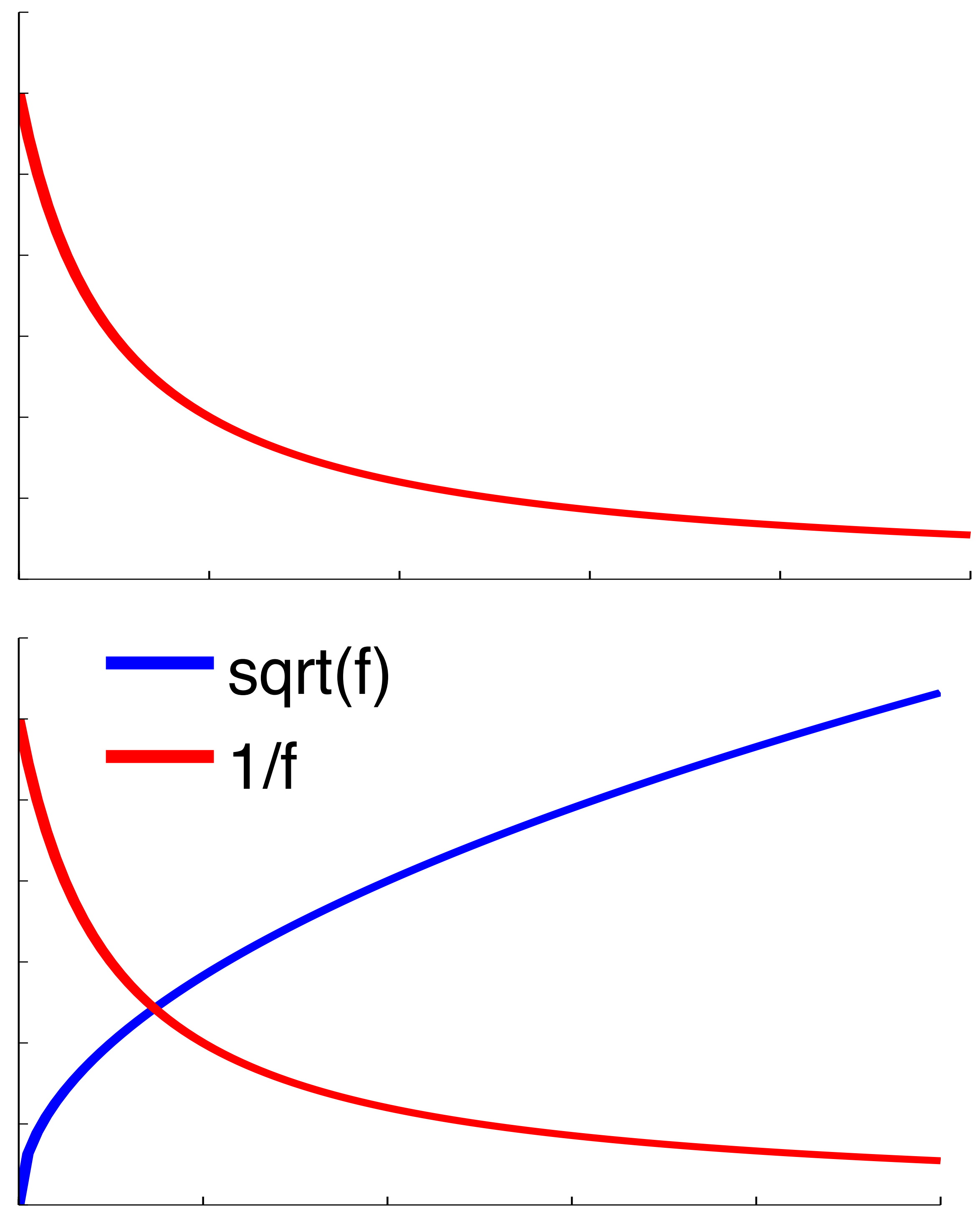
Low frequency fluctuations?
低频波动振幅?

- BOLD decreases as 1/*f*

  BOLD降低1 / f

- Degrees of freedom increase as sqrt(*f*)

  自由度增加为sqrt（f）



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- BOLD decreases as 1/*f*

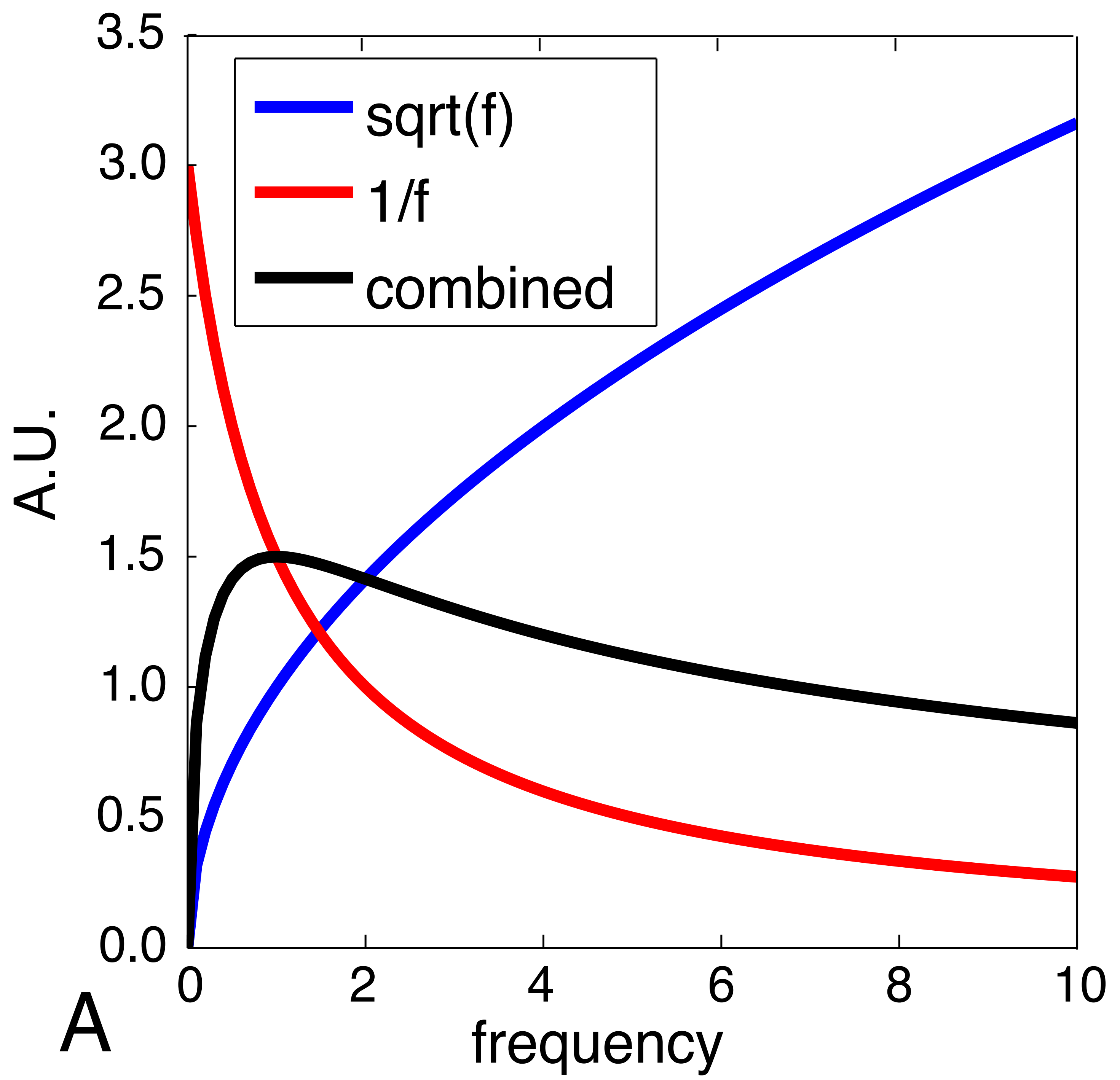
  BOLD降低1 / f

- Degrees of freedom increase as sqrt(*f*)

  自由度增加为sqrt（f）

- Combined effect contributes to RSN estimation across frequency range!

  联合效应有助于跨频率范围的RSN估计！



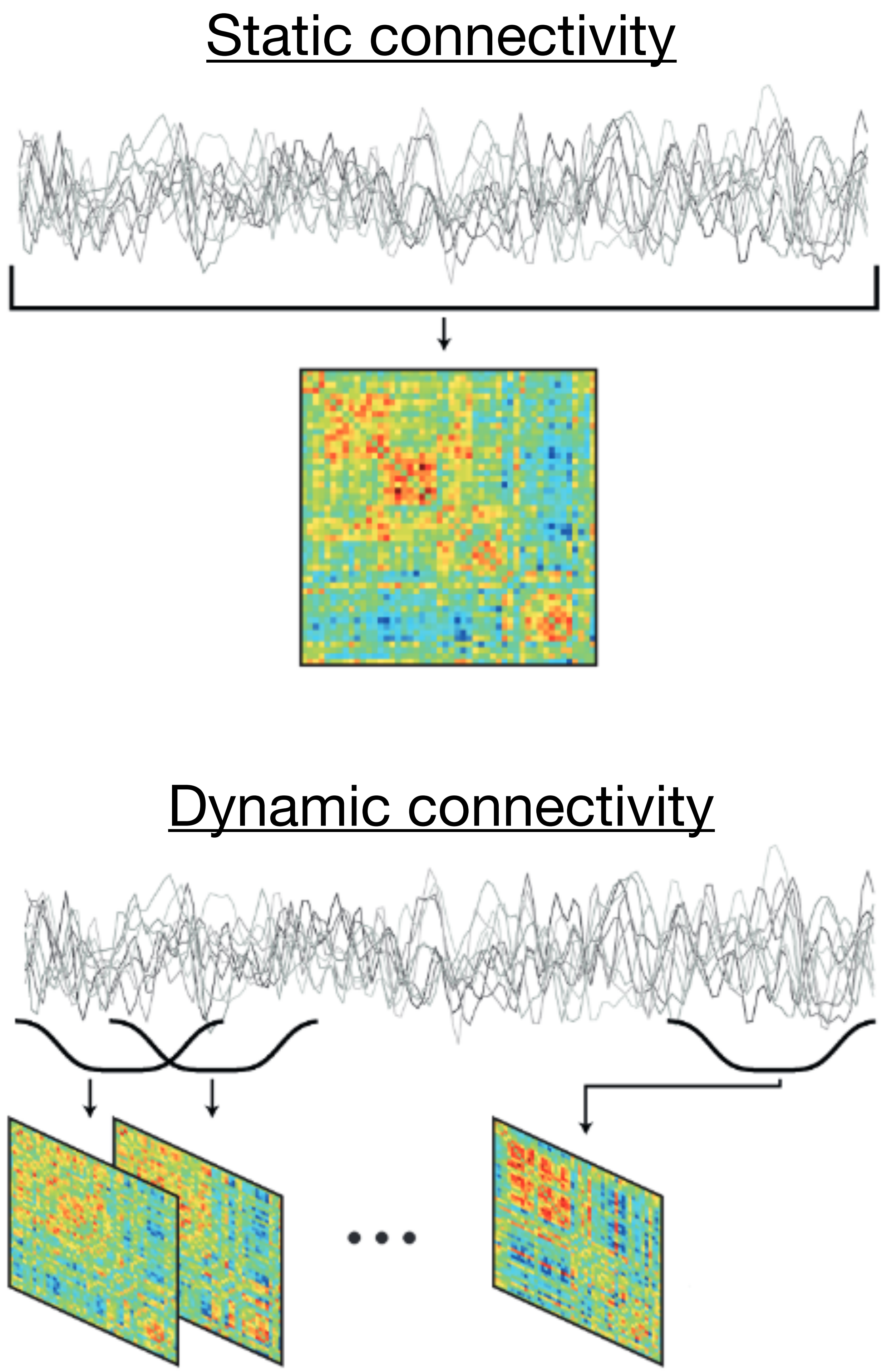
Static versus dynamic connectivity
静态与动态连接

- Most connectivity measures are static (based on the full resting state scan) 大多数连接度量是静态的（基于完全静止状态扫描）

- Dynamic connectivity is like to occur (changes over time) 动态连接似乎会发生（随时间变化)

- Static connectivity measures reflect average across dynamic states 静态连接度量反映了动态的平均值

- Dynamic connectivity measures are challenging (in terms of noise influences, significance testing) 动态连接测量具有挑战性（在噪声和显著性检验方面）



Allen et al (2012), Hutchison et al (2013)

Arousal 觉醒

- Subjects fall asleep 受试者入睡

Tagliazucchi and Laufs (2014), Horovitz et al (2008), Bijsterbosch et al (2017)

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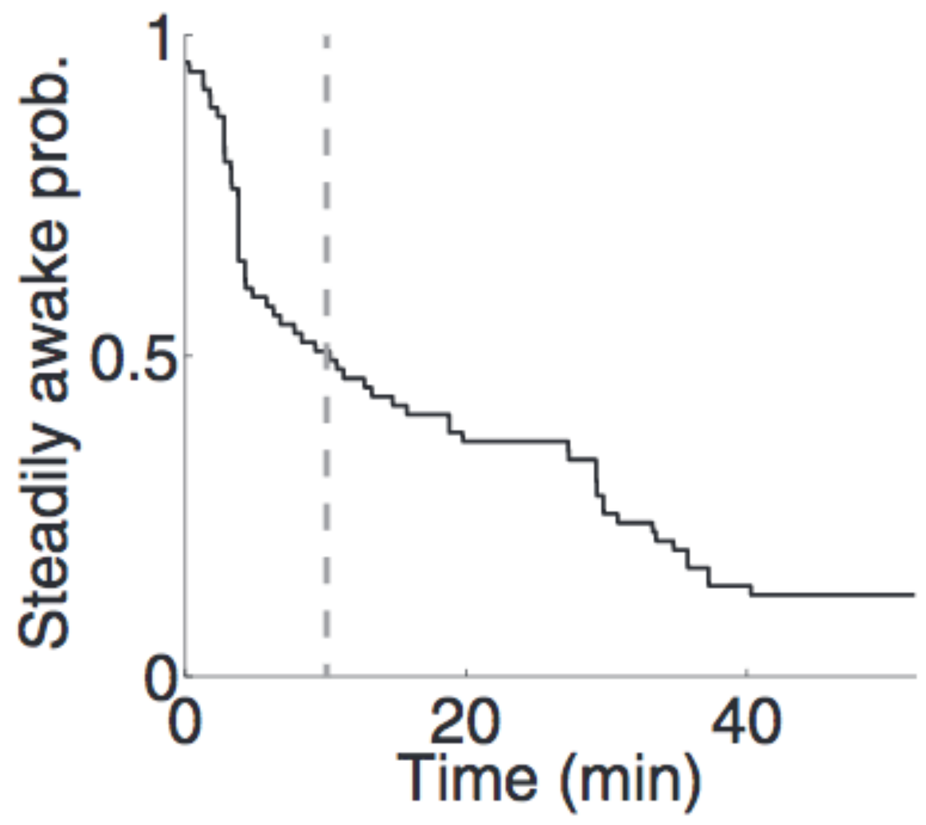
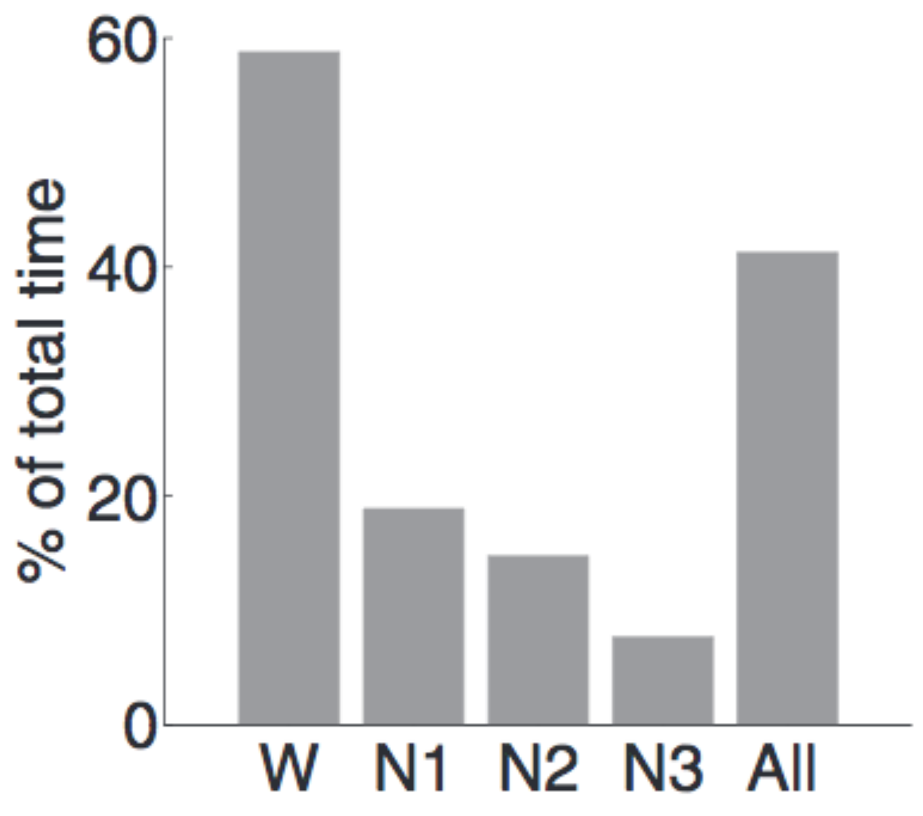
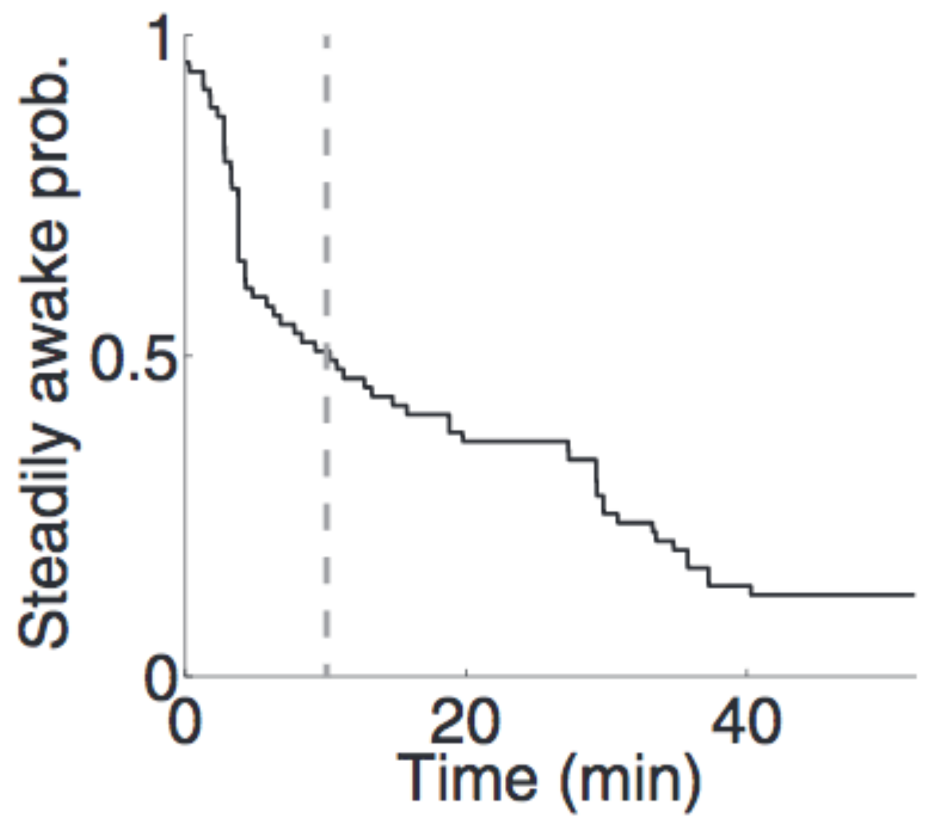


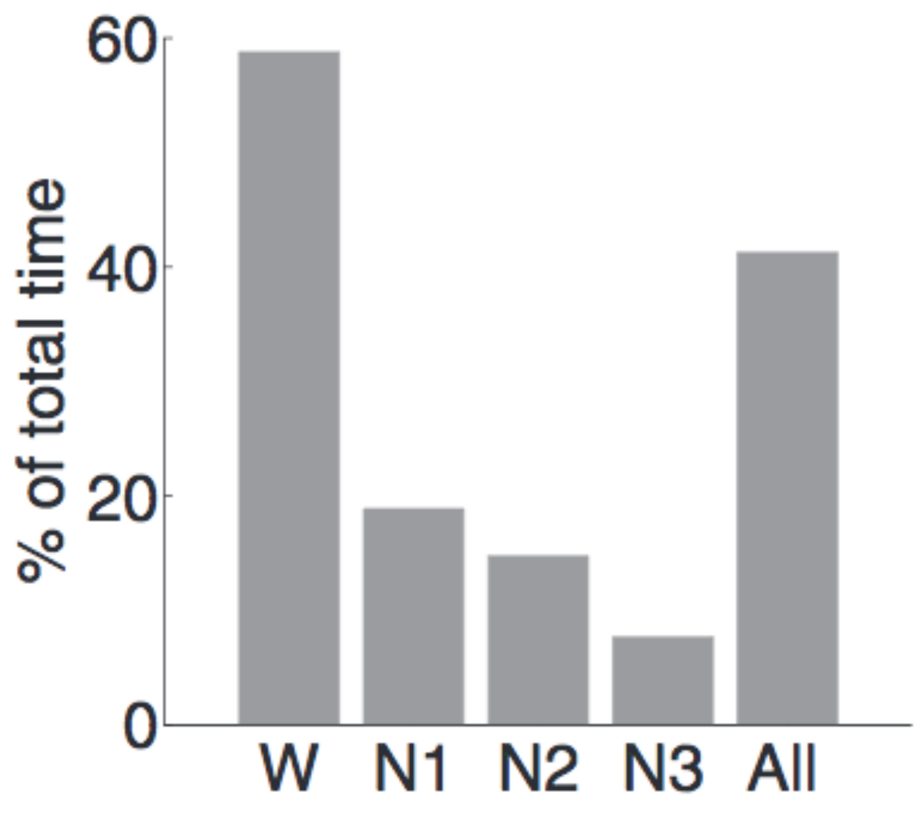


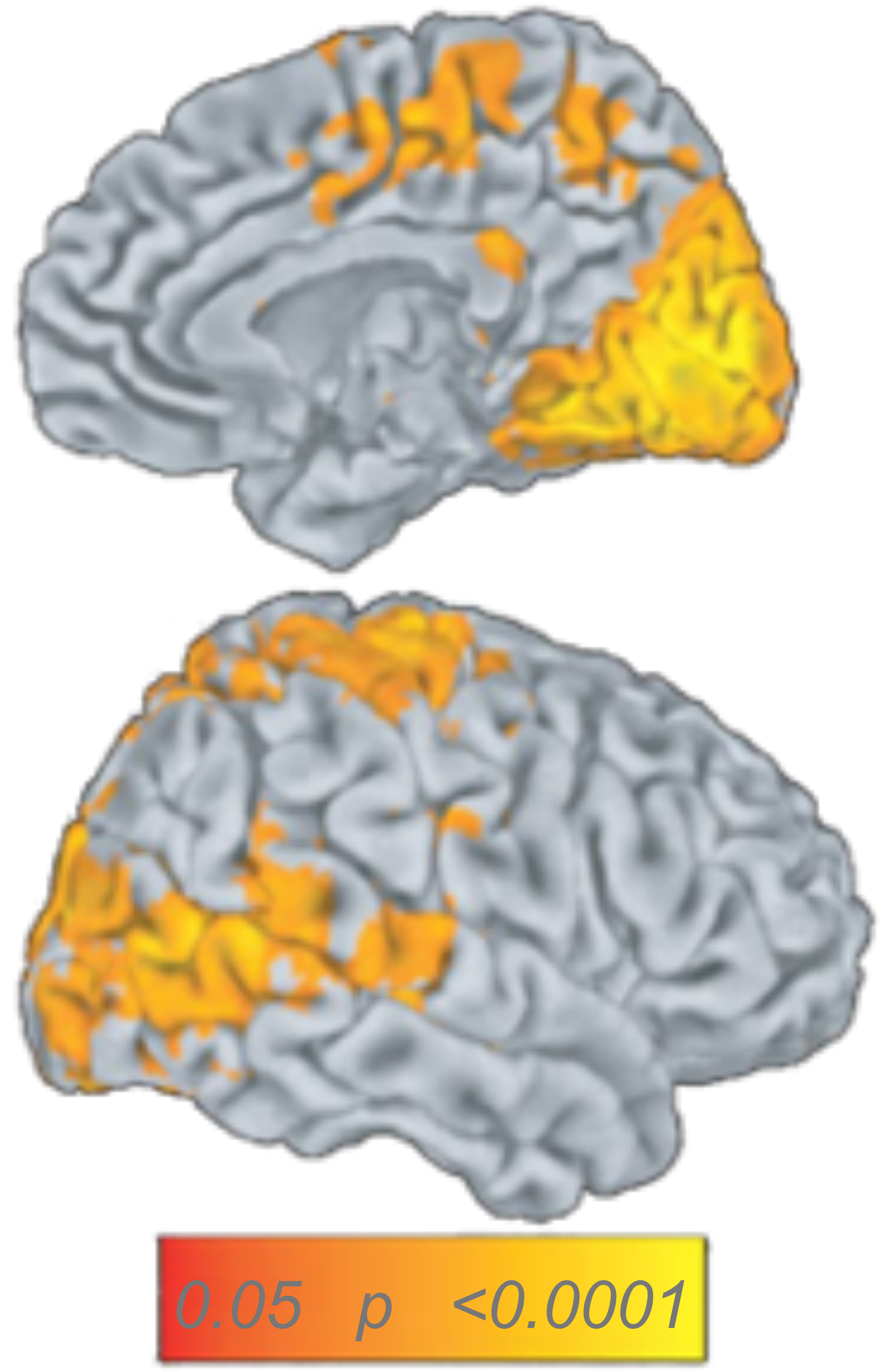
Tagliazucchi and Laufs (2014), Horovitz et al (2008), Bijsterbosch et al (2017)

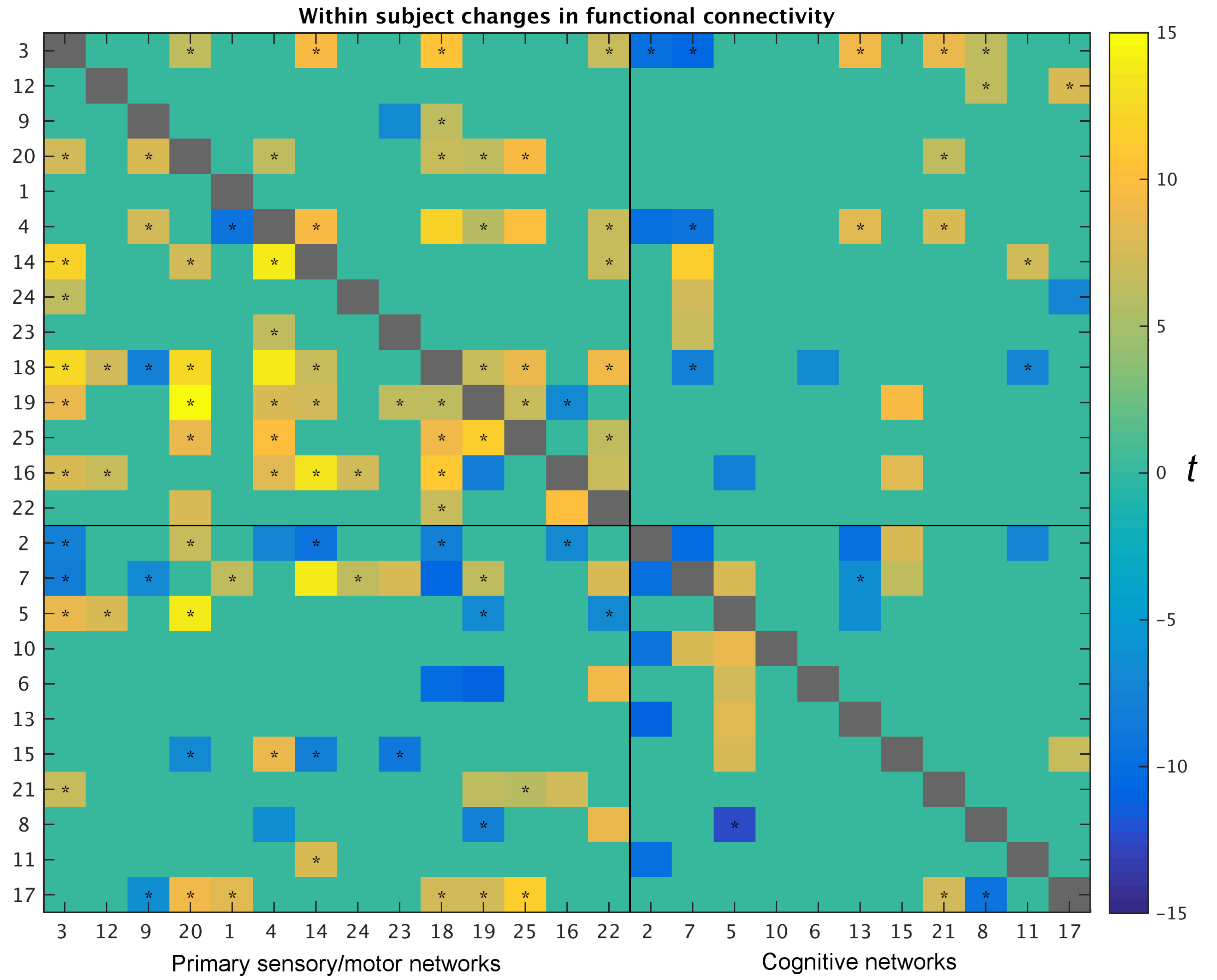
Arousal 觉醒

- Subjects fall asleep 受试者入睡
- Changes in BOLD amplitude
  BOLD幅度的变化
- Related changes in correlation
  相关性变化









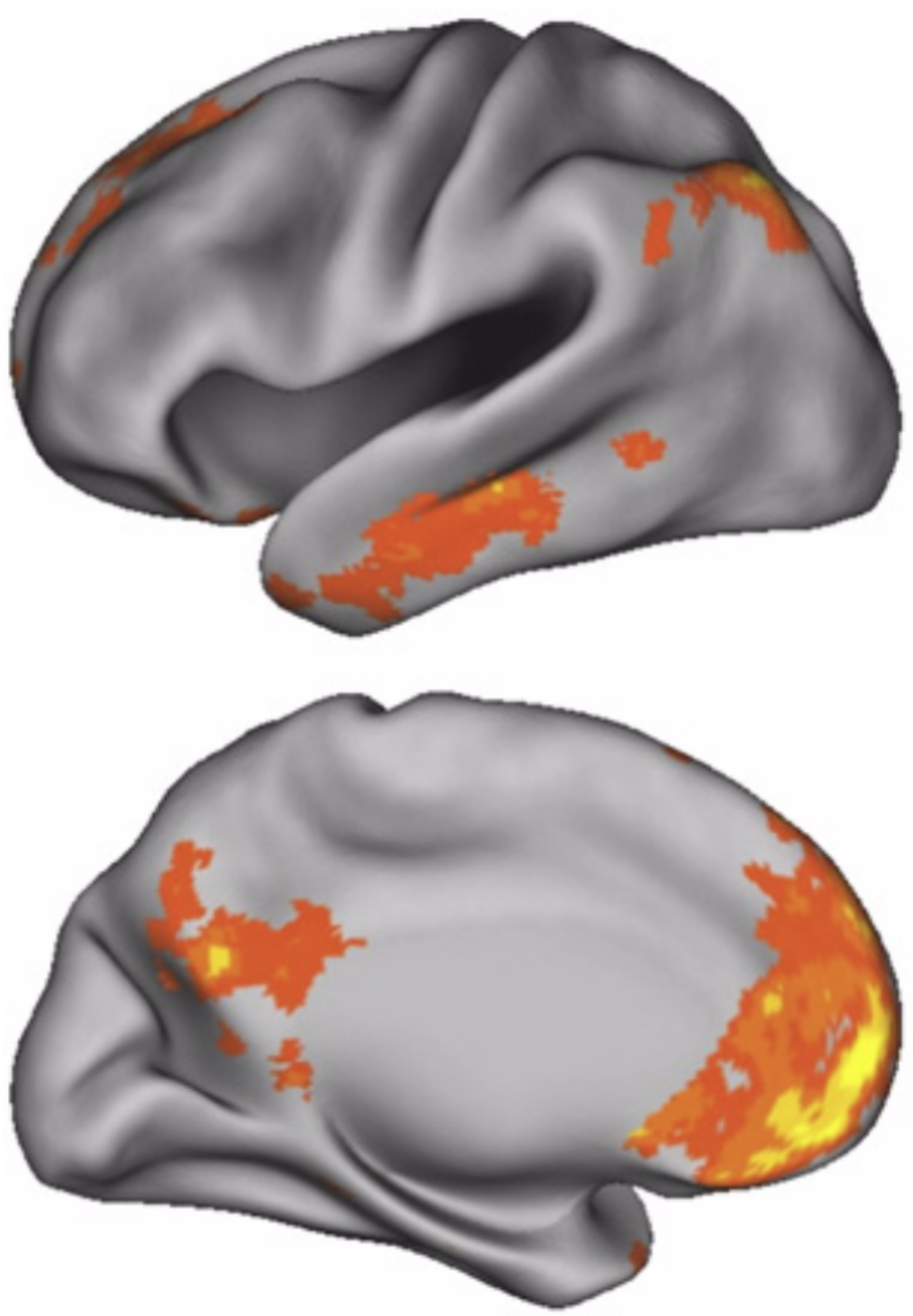
Tagliazucchi and Laufs (2014), Horovitz et al (2008), Bijsterbosch et al (2017)

Preprocessing
预处理

Careful cleanup required
需要仔细去噪

- Structured artefacts much more of a problem for rfMRI than task-fMRI rfMRI比task-fMRI存在更多的人为因素
- No model of expected activation 没有预期激活的模型
  - Instead based on correlating timeseries with each other 而是基于将时间序列相互关联

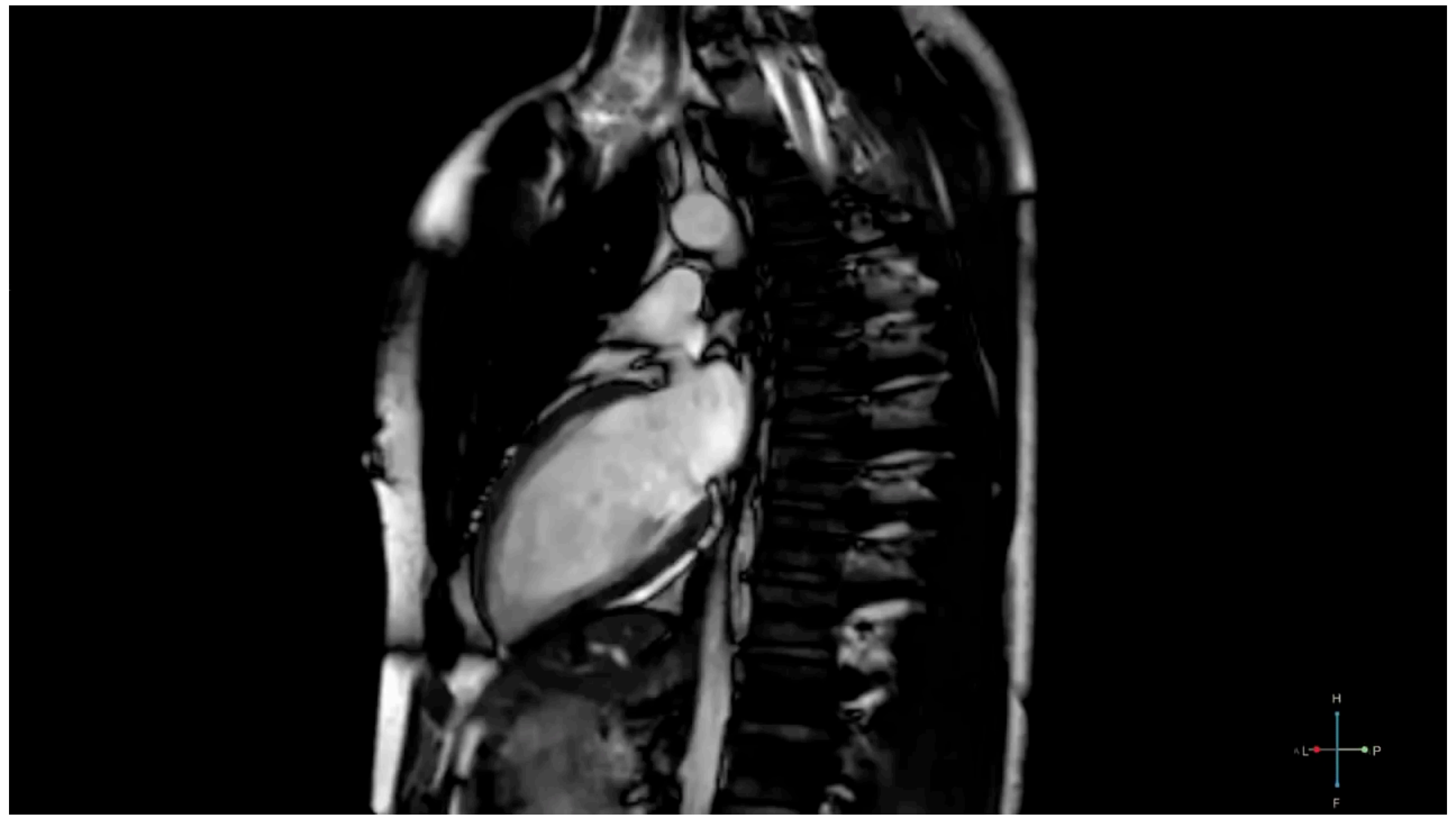
Low motion > high motion

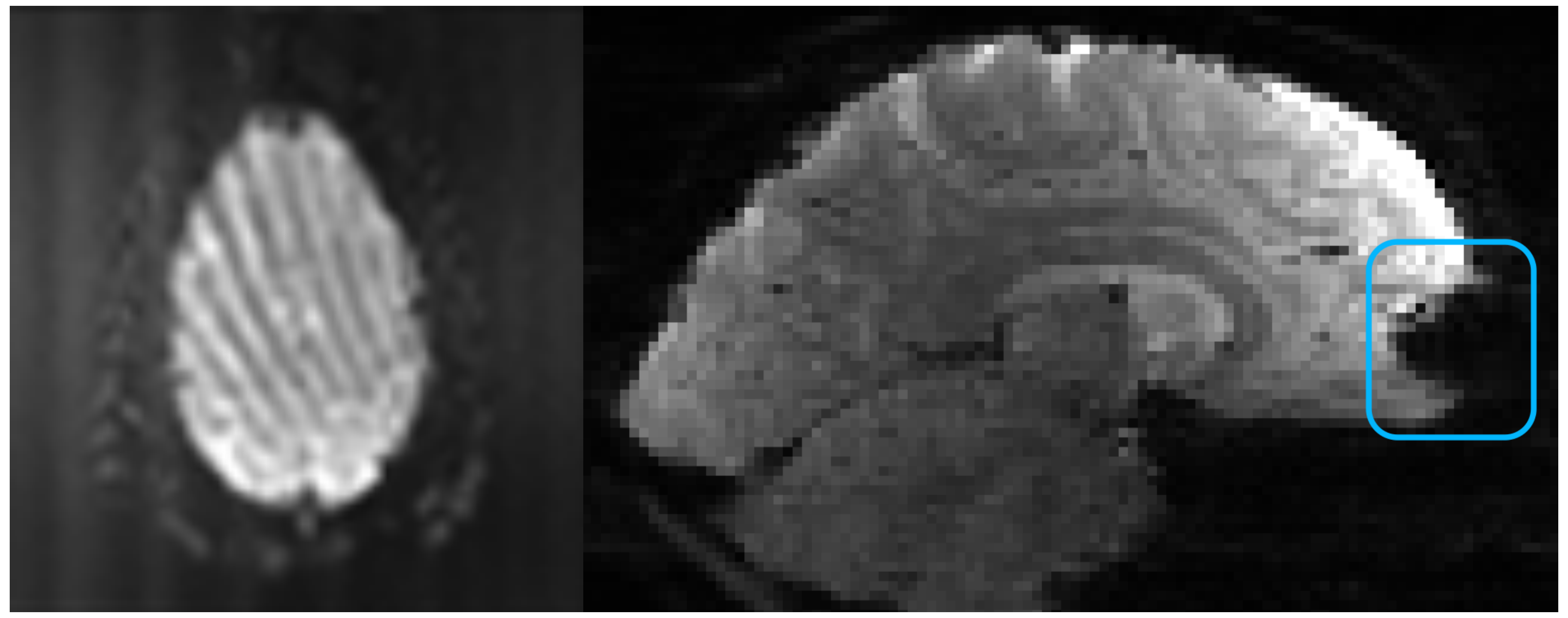


Van Dijk et al (2012)

Noise sources
噪声来源

- Head motion 头动
- Cardiac & breathing cycles 心跳和呼吸周期
- Scanner artefacts 扫描仪噪声





Preprocessing overview
预处理概述

Conventional preprocessing steps
常规预处理步骤

- 头动&失真校正 — Motion & distortion correction
- Slice timing correction — 时间层校正
- 高通滤波 — High pass temporal filtering
- Spatial smoothing — 空间平滑
- 配准 — Registration

Noise reduction steps (use at least one of these)
降噪步骤（至少使用其中之一）

- 噪声回归 — Nuisance regression
- Low pass temporal filtering — 低通滤波
- 全脑检查 — Volume censoring
- Global signal regression — 全脑信号回归
- ICA降噪 — ICA-based clean-up
- 去除生理噪声 — Physiological noise regression

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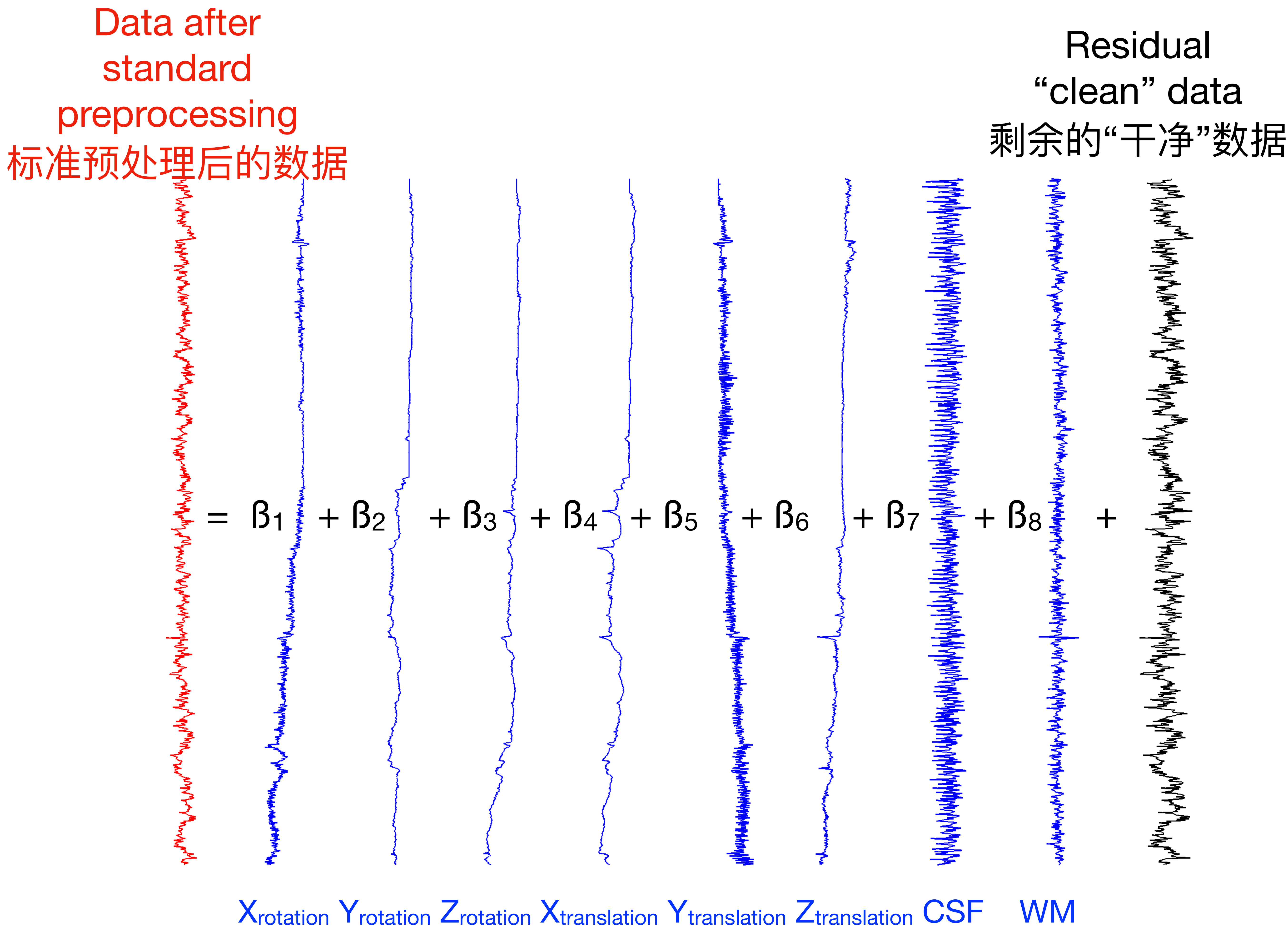
噪声回归	Nuisance regression	Low pass temporal filtering	低通滤波
全脑检查	Volume censoring	Global signal regression	全脑信号回归
ICA降噪	ICA-based clean-up		
去除生理噪声	Physiological noise regression		

Nuisance regression
噪声回归

- Head motion parameters（头动参数）
- White-matter / CSF（白质/脑脊液）
- Use GLM to remove nuisance timeseries （GLM去除噪声时间序列）
- Perform analysis on residuals
  （残差分析）
- “CompCor” method (PCA-based)
  (“CompCor”方法（基于PCA））



Muschelli et al (2014)

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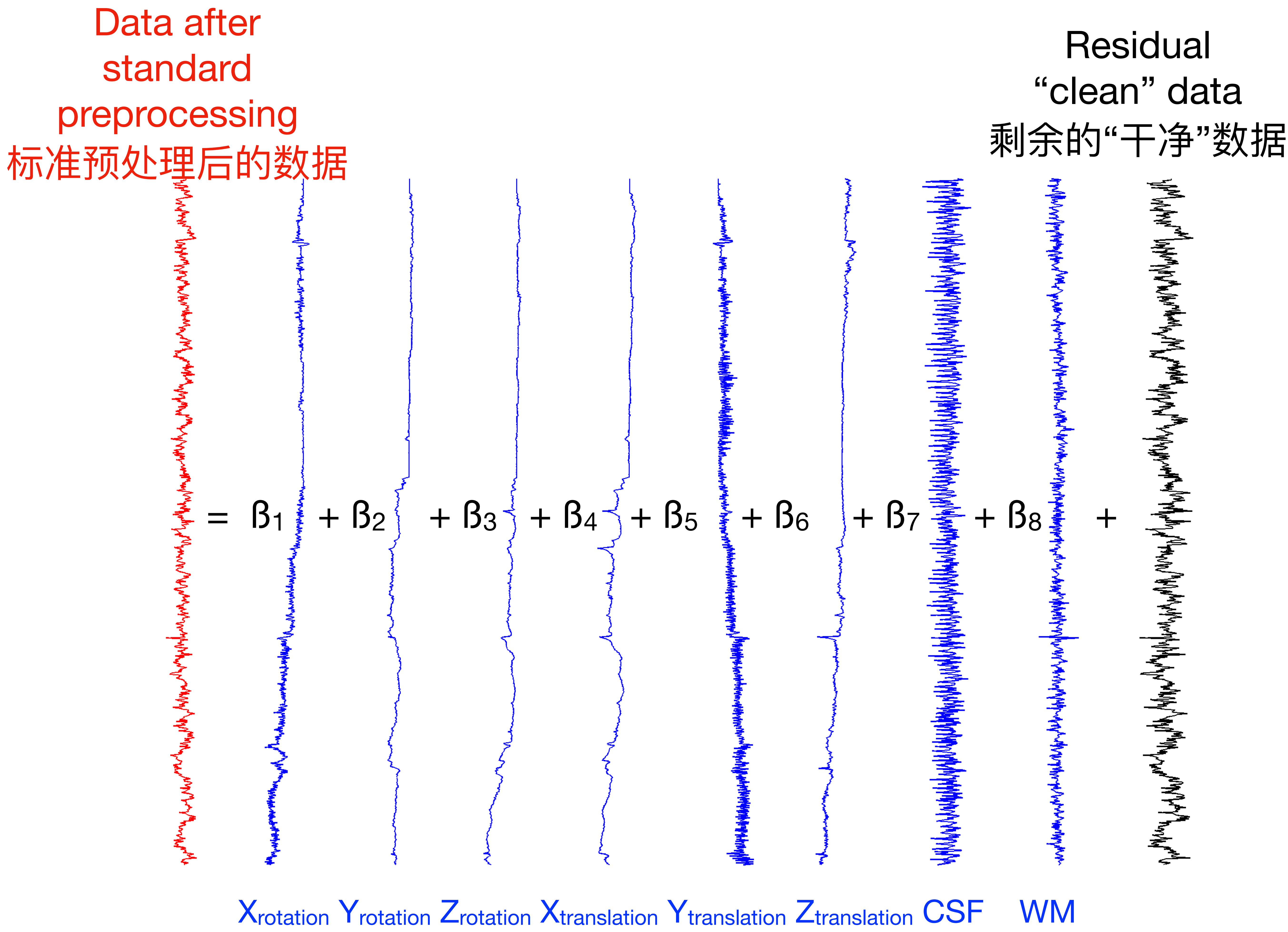
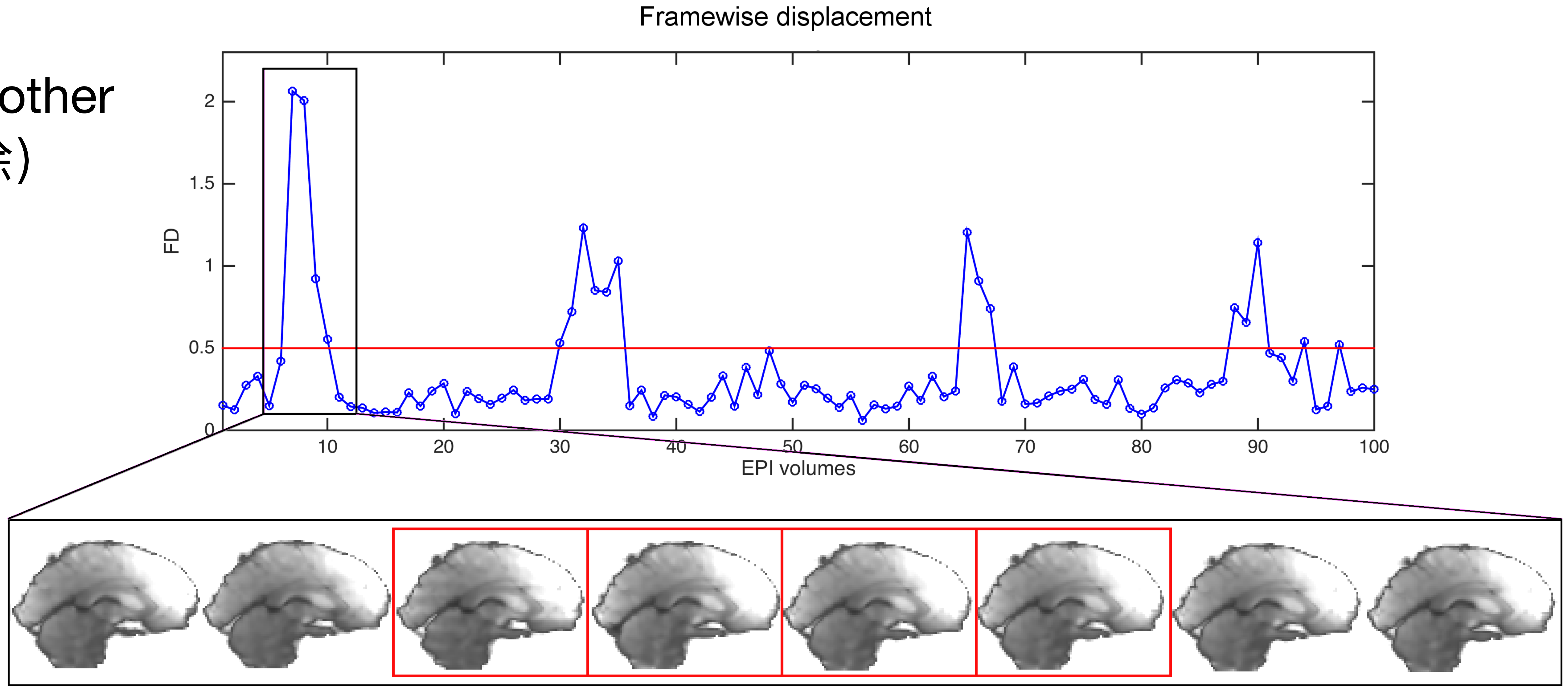


Muschelli et al (2014)

Volume censoring
大脑检查

- Remove volumes with high motion（移除头动较大的图像）
- Very effective to fully remove large motion effects（移除头动较大的体素效果很好）
- But, does not remove small motion effects and other noise sources （头动小的以及其他噪声不要移除）
- Also known as scrubbing, spike regression, de-spiking
  也称为去噪，尖峰回归，去尖峰



Power et al (2012, 2013, 2014, 2015)

ICA based cleanup

ICA降噪

- Semi-Automatic labelling methods available (ICA-FIX, ICA-AROMA)

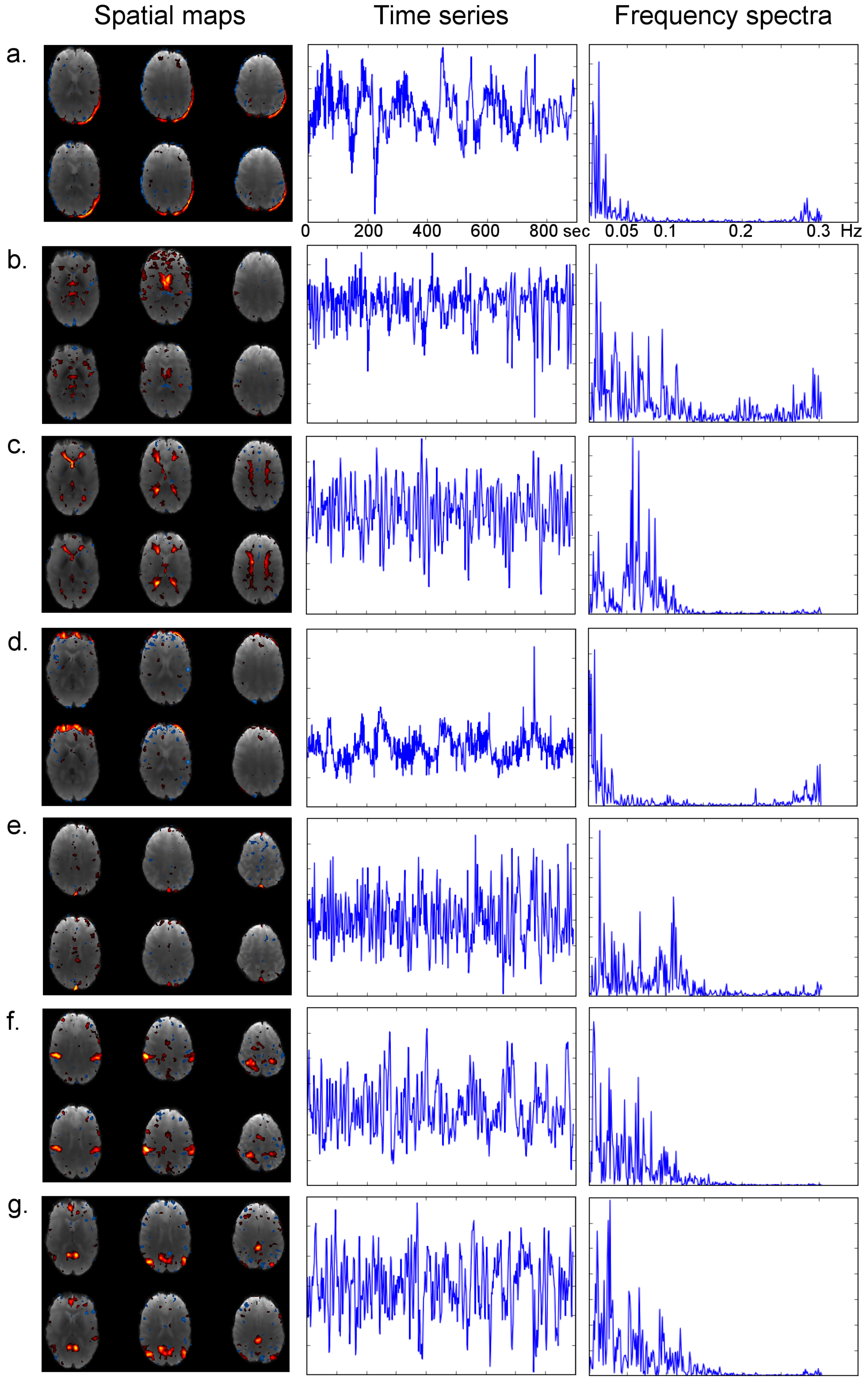
  半自动标记的方法 (ICA-FIX, ICA-AROMA)

- Removes most types of artefacts (motion, physiology, scanner)

  删除大多数类型的噪声（头动、生理、扫描设备）

- But, does not capture global (spatially extended) noise

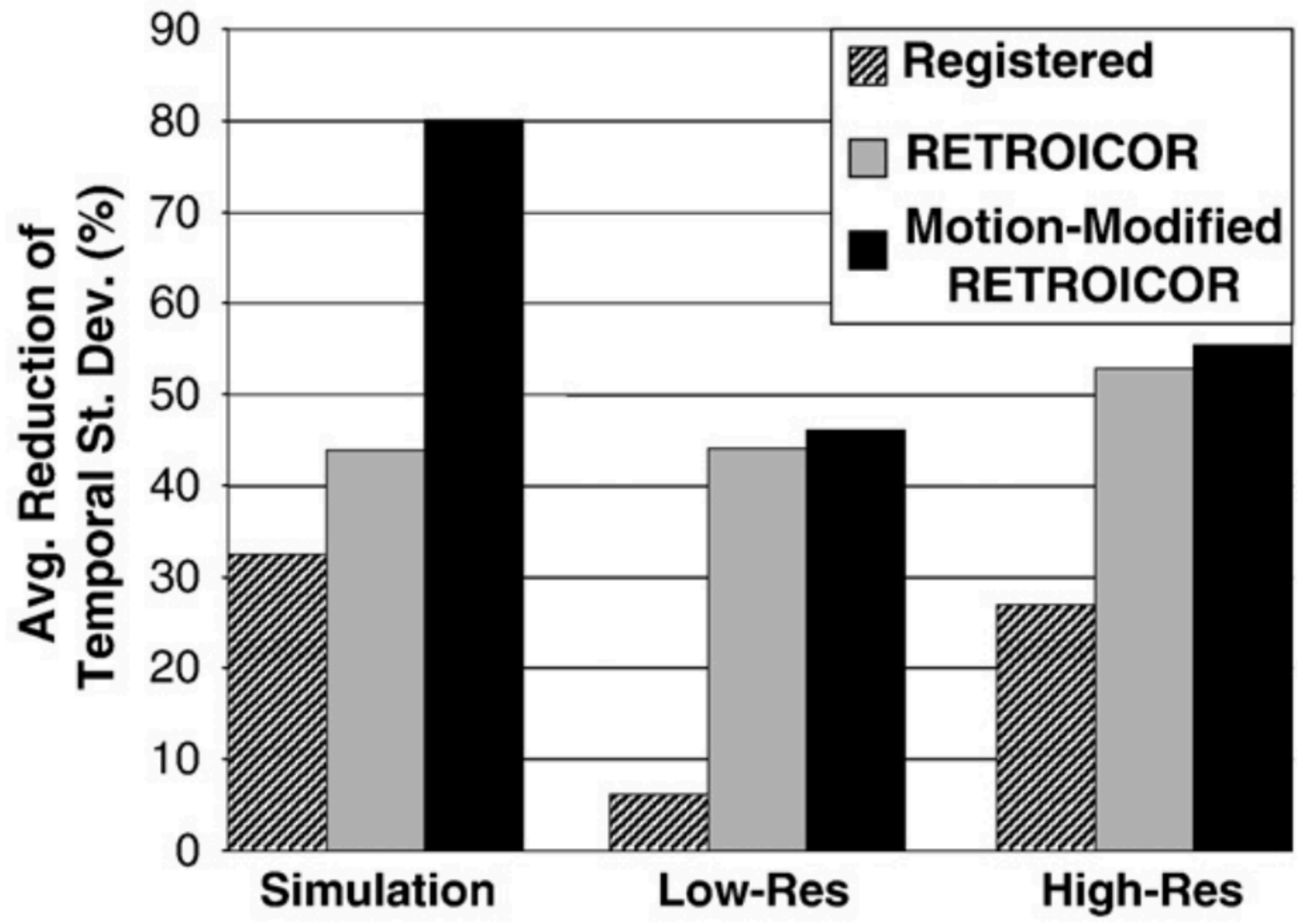
  但是，不会删除全局（空间扩展）噪声



Salimi-Khorshidi et al (2014), Pruim et al (2015)

Physiological noise regression
去除生理噪声

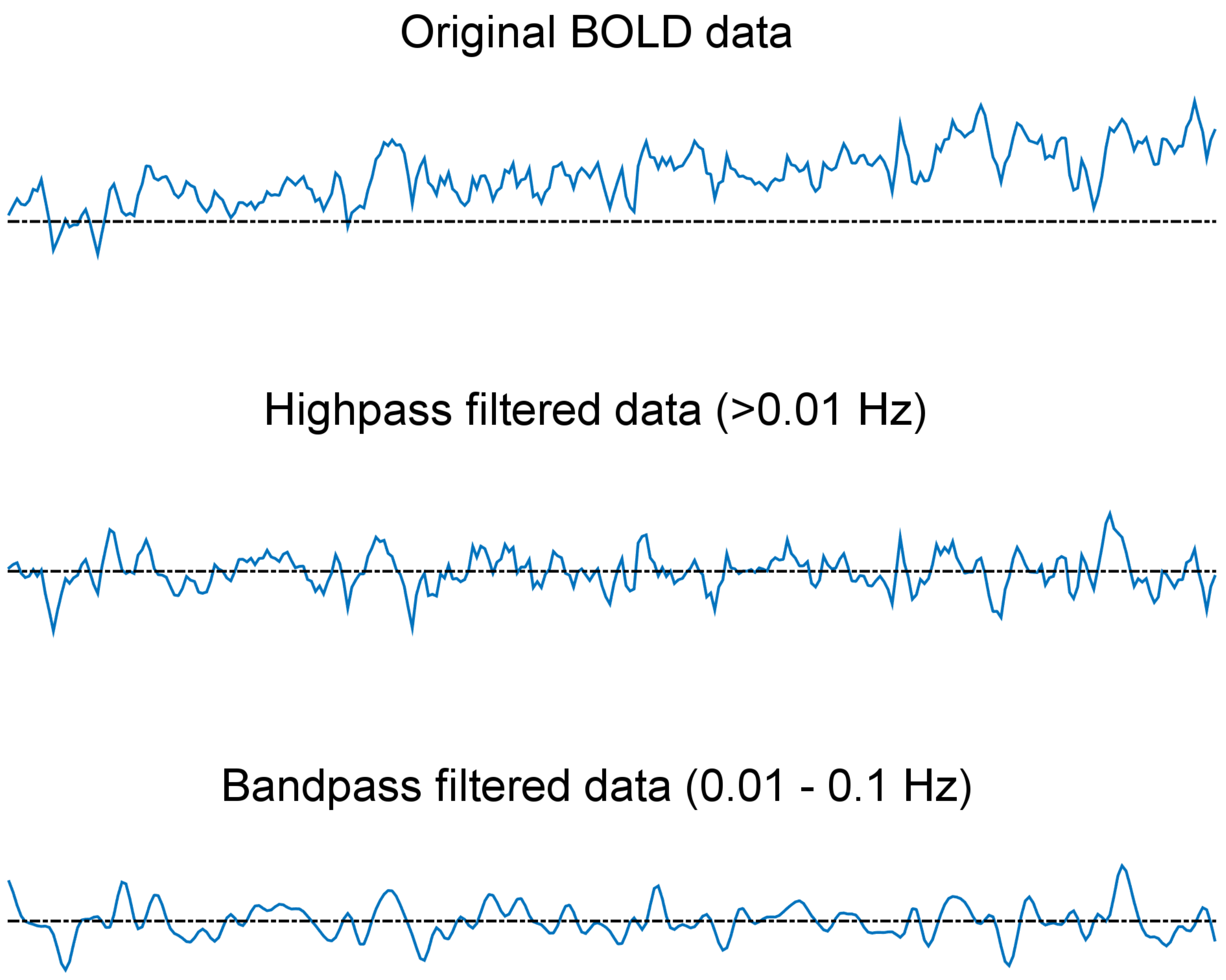
- PNM, RETROICOR
- Requires physiological measurements during scan 在扫描期间需要生理信号测量
- Generates regressors based on physiological data 基于生理数据生成回归量



Glover et al (2000), Jones et al (2008)

Lowpass temporal filtering
低通时间滤波

- E.g., common to remove frequencies > 0.1Hz
  通常去除> 0.1Hz的频率
- May remove useful signal
  可能会删除有用信号
- Not guaranteed to remove much artefact
  不能保证删除很多噪声

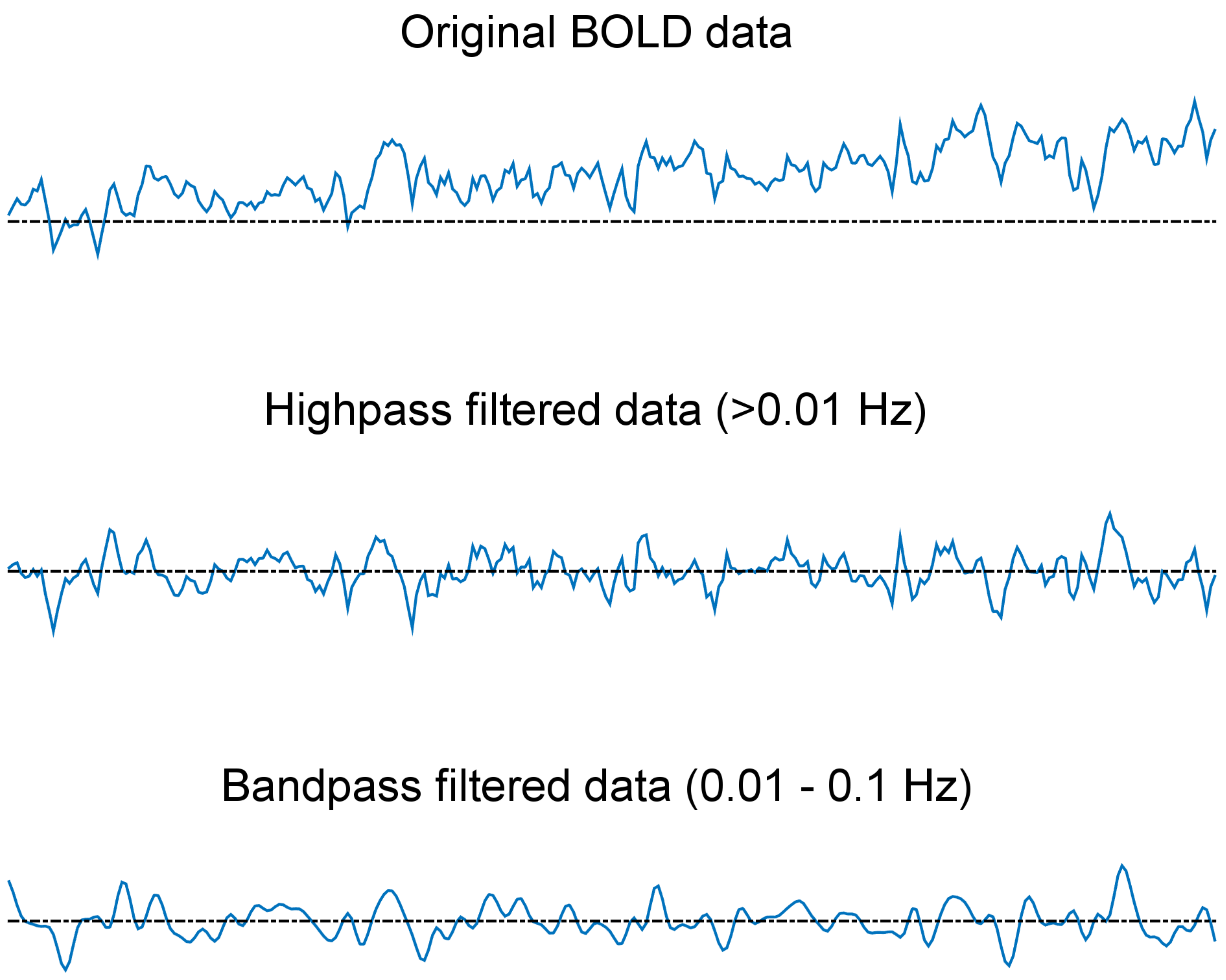


Lowpass temporal filtering
低通时间滤波

- E.g., common to remove frequencies > 0.1Hz
  通常去除> 0.1Hz的频率

- May remove useful signal
  可能会删除有用信号

- Not guaranteed to remove much artefact
  不能保证删除很多噪声



Global signal regression

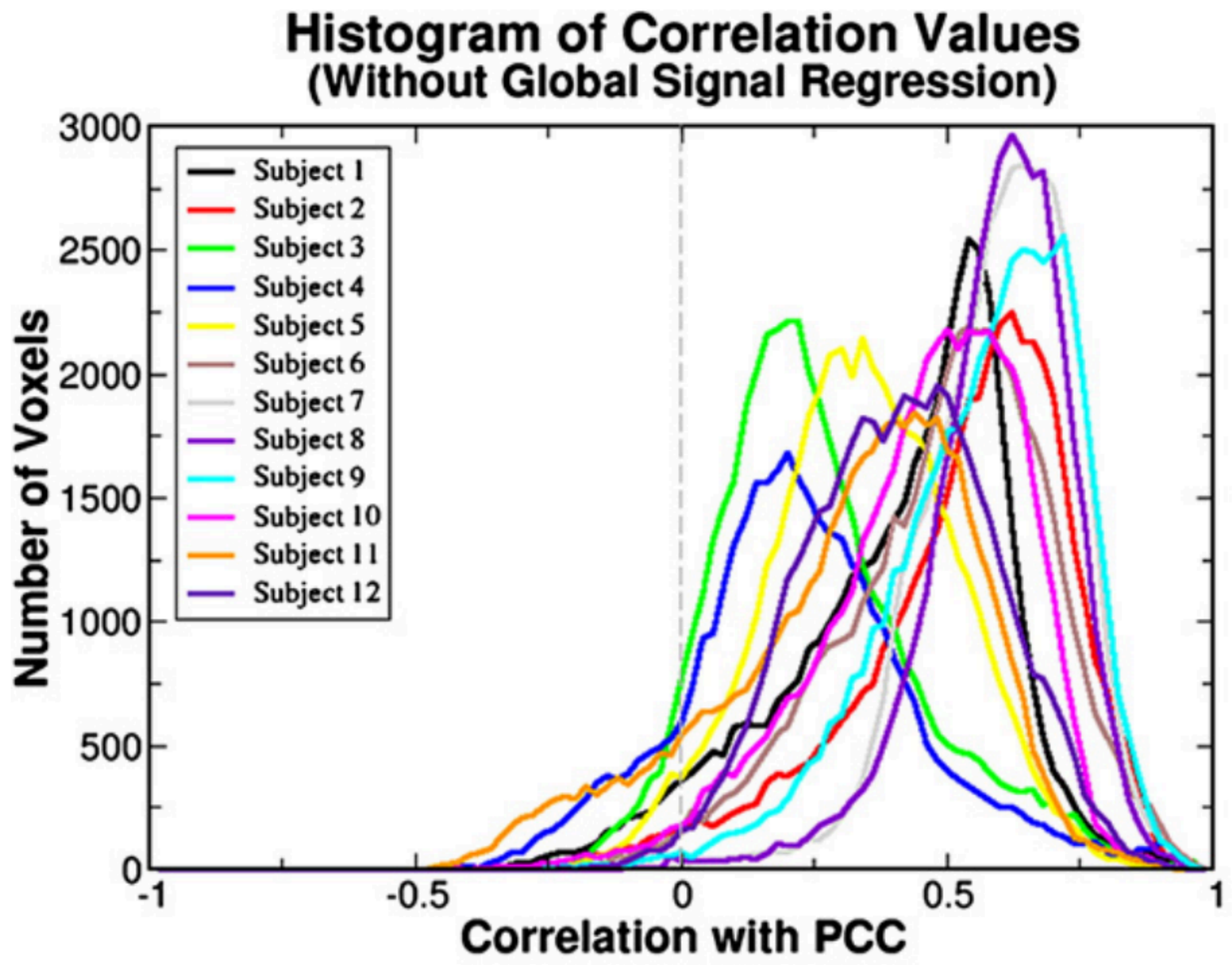
去除全脑信号

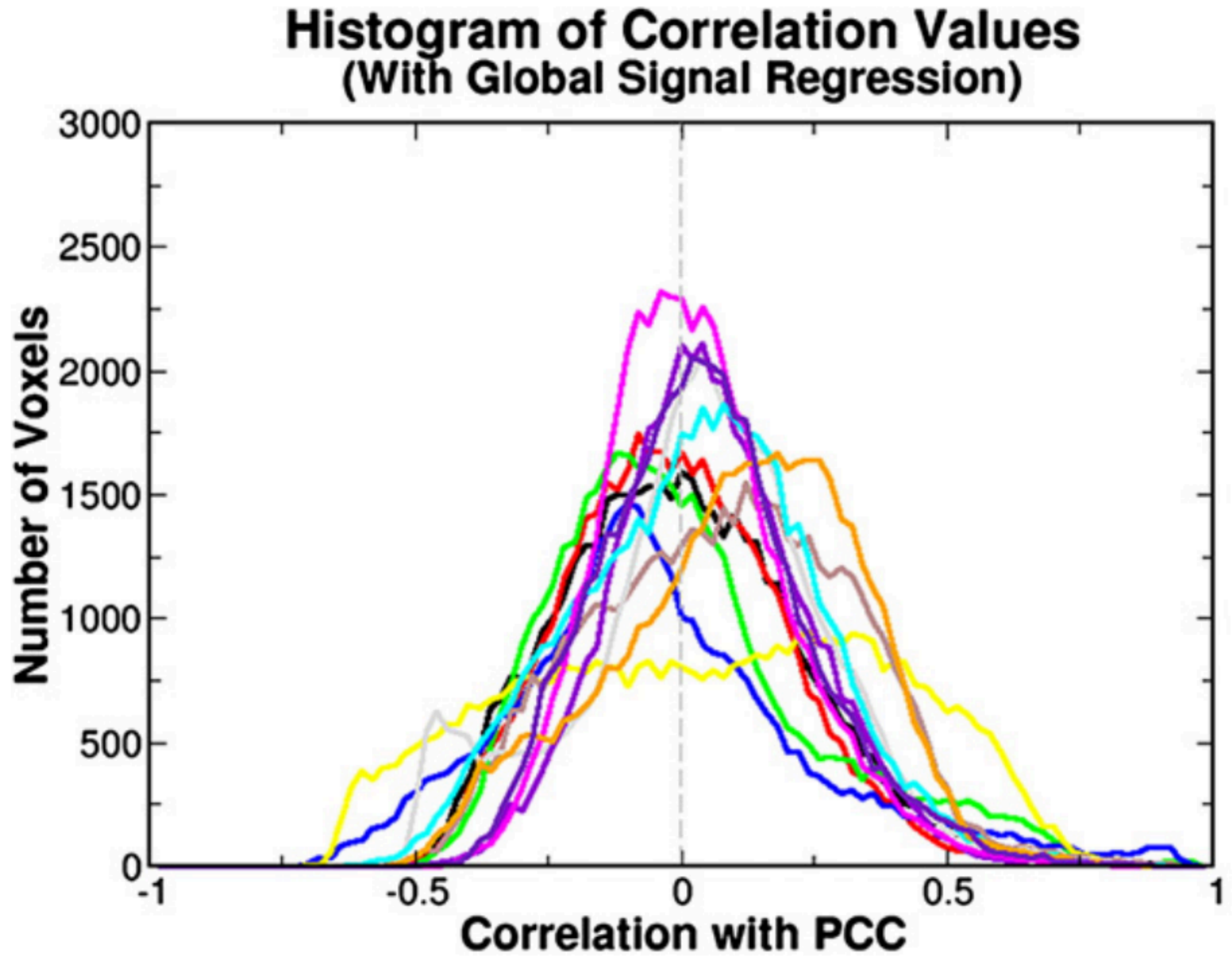
- Regress out mean timeseries across all voxels (or all grey matter voxels)
  回归所有体素（或所有灰质体素）的平均时间序列

- Shifts connectivity values to be zero mean
  将连通性值转换为零均值

- Therefore, more negative correlations
  因此，存在更多的负相关

- Not necessary if using partial correlation
  如果使用偏相关则不必要

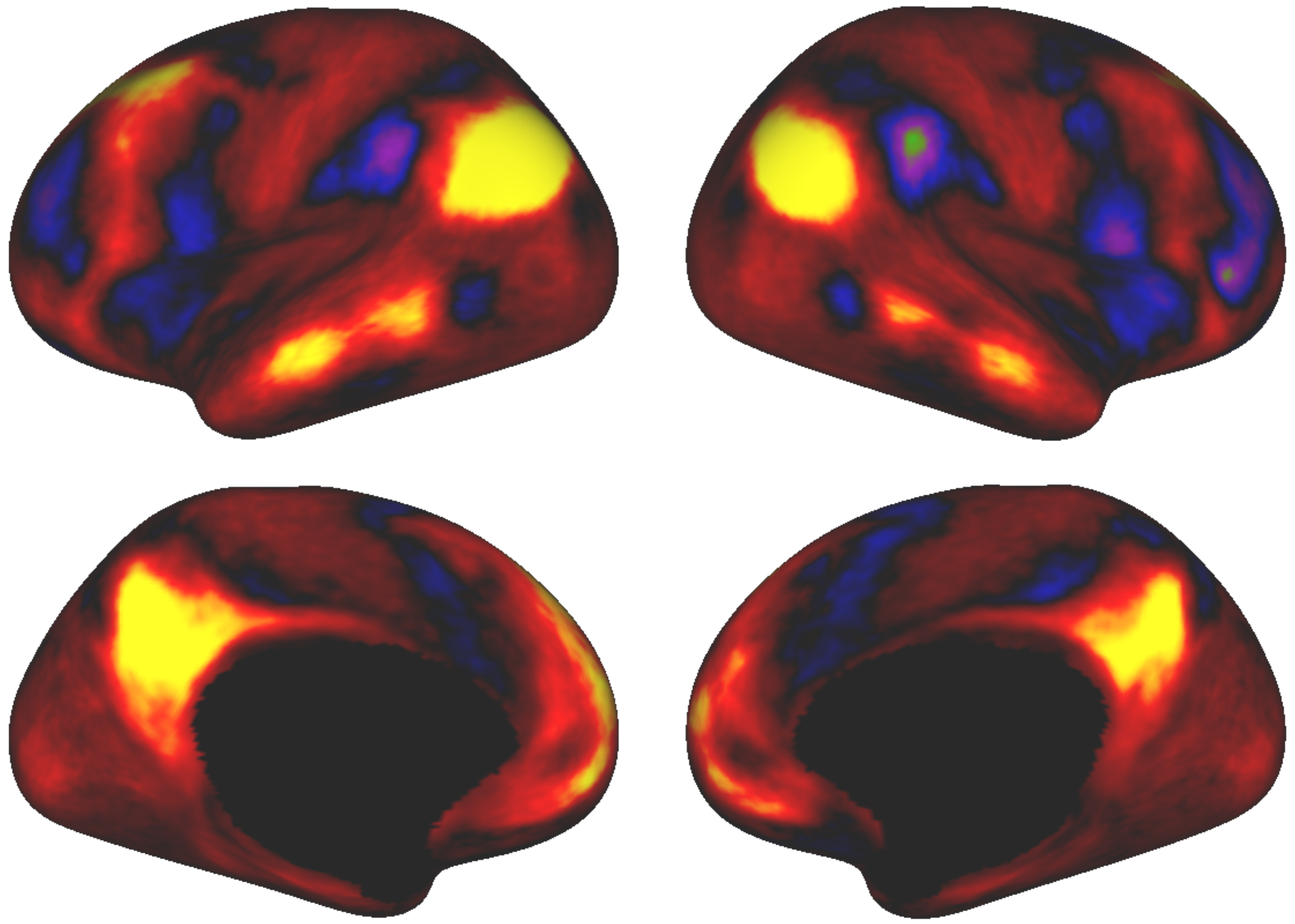




Murphy et al (2009)

GSR effects & alternative

去除全脑信号效应和替代方法

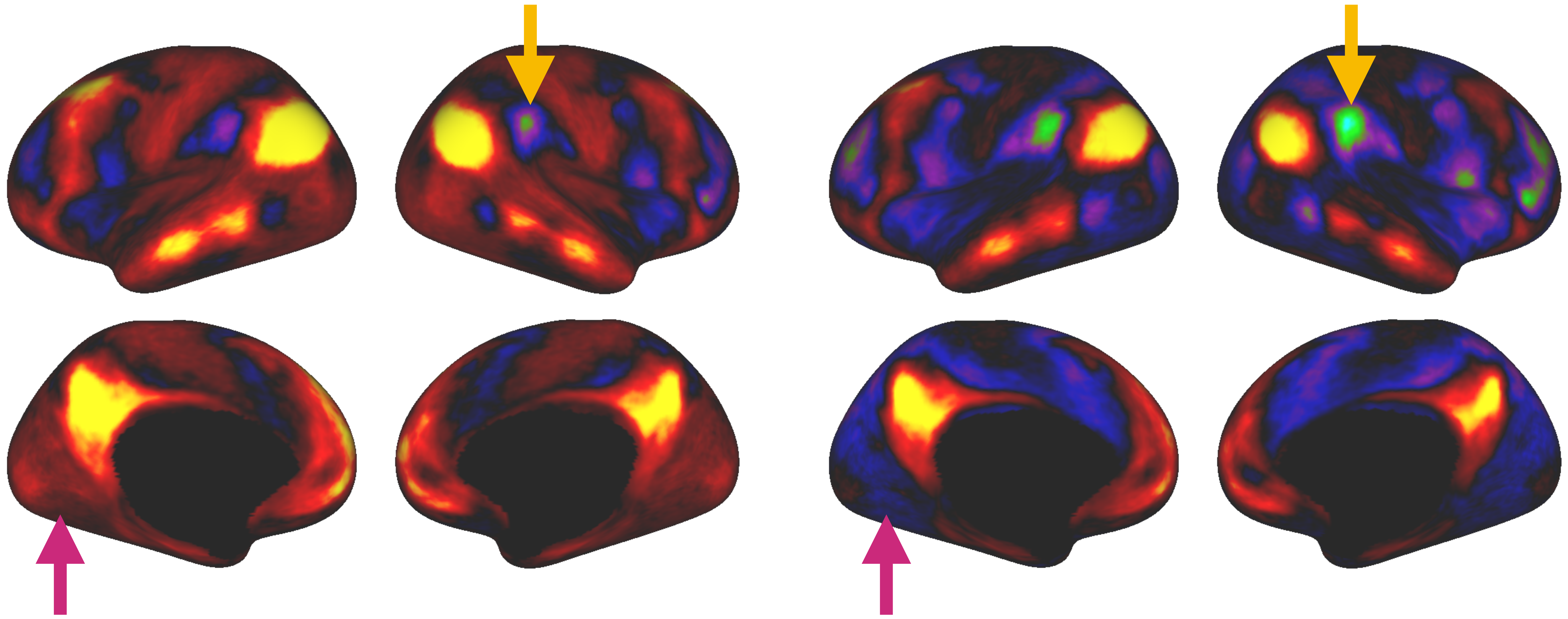


PCC correlation
spatial ICA cleanup
PCC 相关
空间ICA去噪

Glasser et al (2018)

GSR effects & alternative

去除全脑信号效应和替代方法



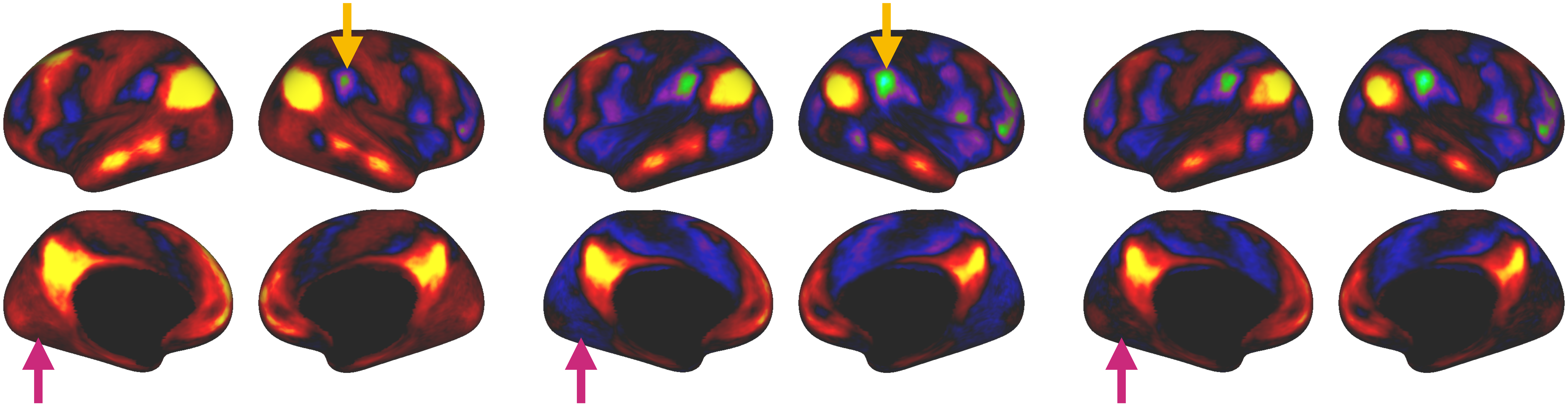
PCC correlation
spatial ICA cleanup
PCC 相关
空间ICA去噪

PCC correlation
spatial ICA cleanup + GSR
PCC 相关
空间ICA去噪 + GSR

Glasser et al (2018)

GSR effects & alternative

去除全脑信号效应和替代方法



PCC correlation
spatial ICA cleanup
PCC 相关
空间ICA去噪

PCC correlation
spatial ICA cleanup + GSR
PCC 相关
空间ICA去噪 + GSR

PCC correlation
spatial ICA cleanup + temporal ICA cleanup
PCC相关
空间ICA去噪+时间ICA去噪

Glasser et al (2018)

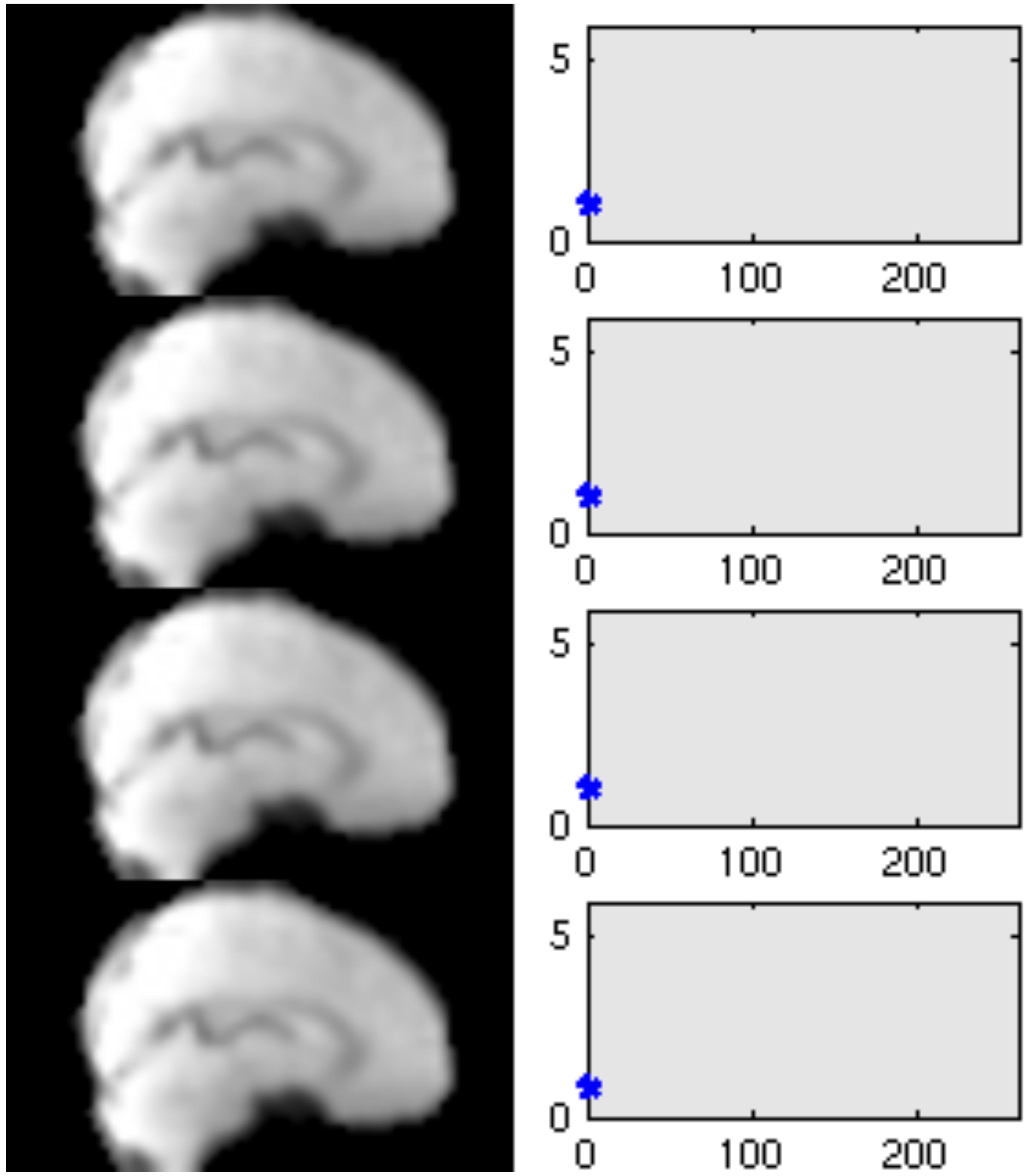
Clean-up comparison
去噪比较

no additional correction
没有使用其他校正方法

24RP-regression
24RP校正

24RP + volume censoring
24RP+体素检查

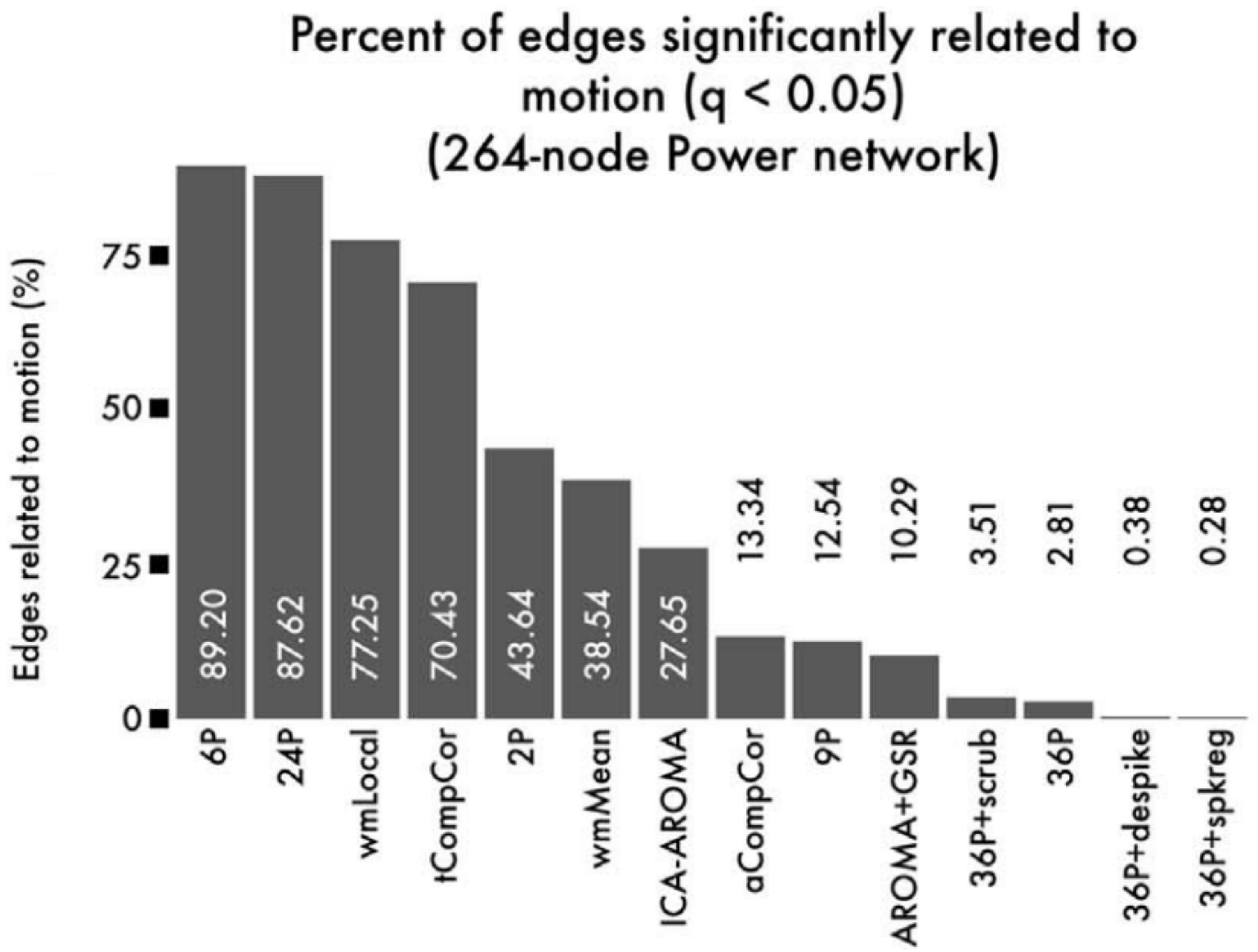
ICA-AROMA

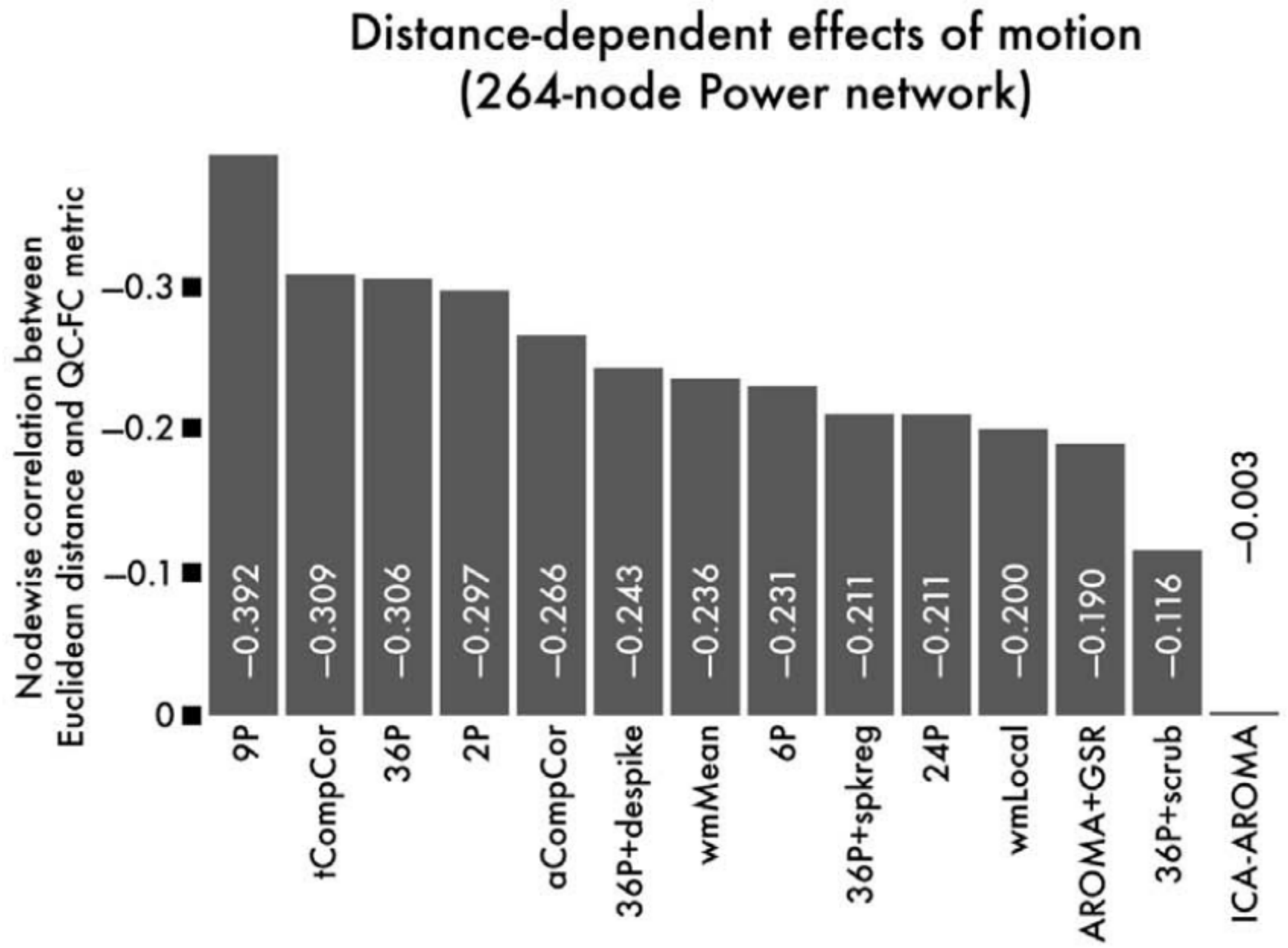


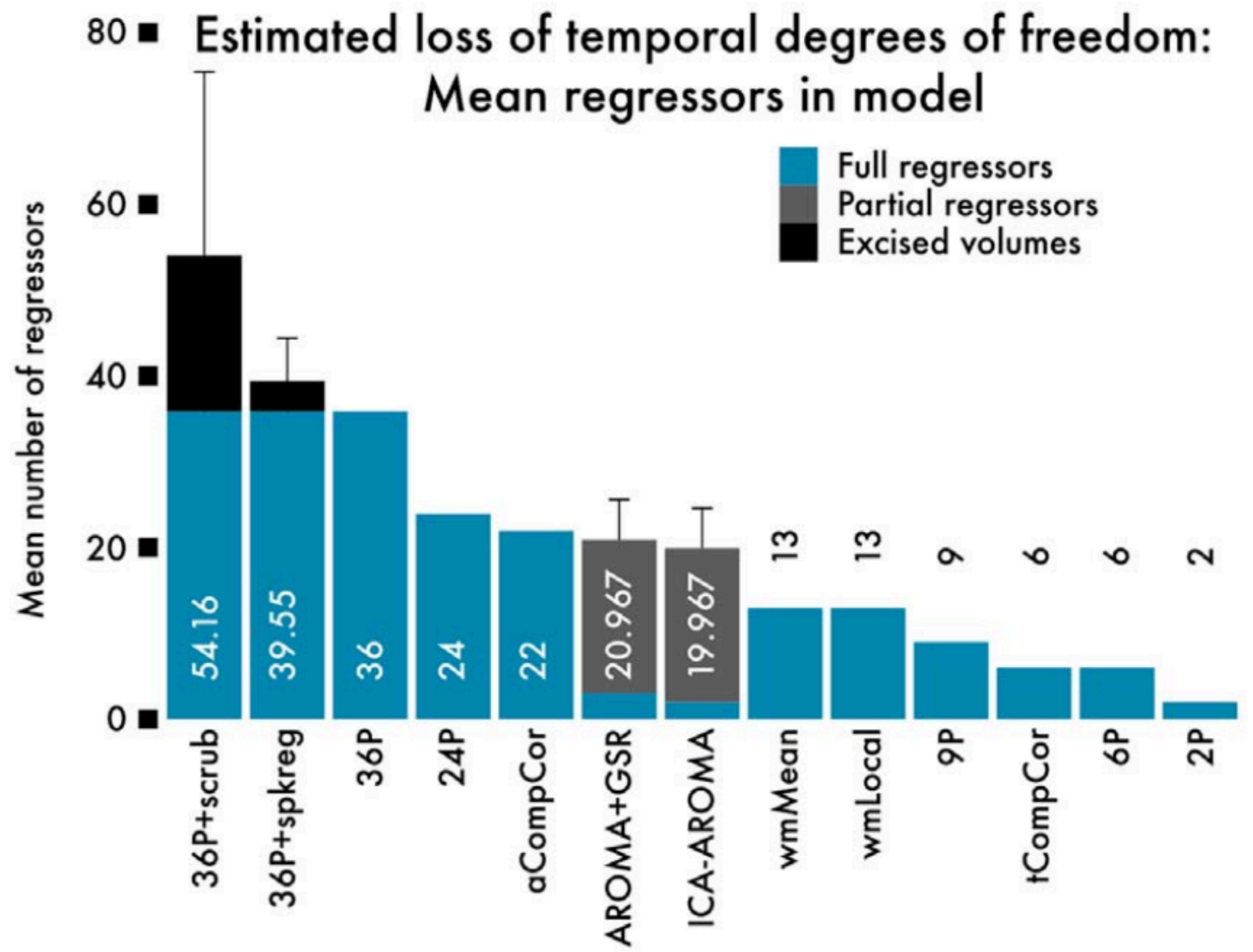
FMRI data DVARS

Clean-up comparison

去噪比较







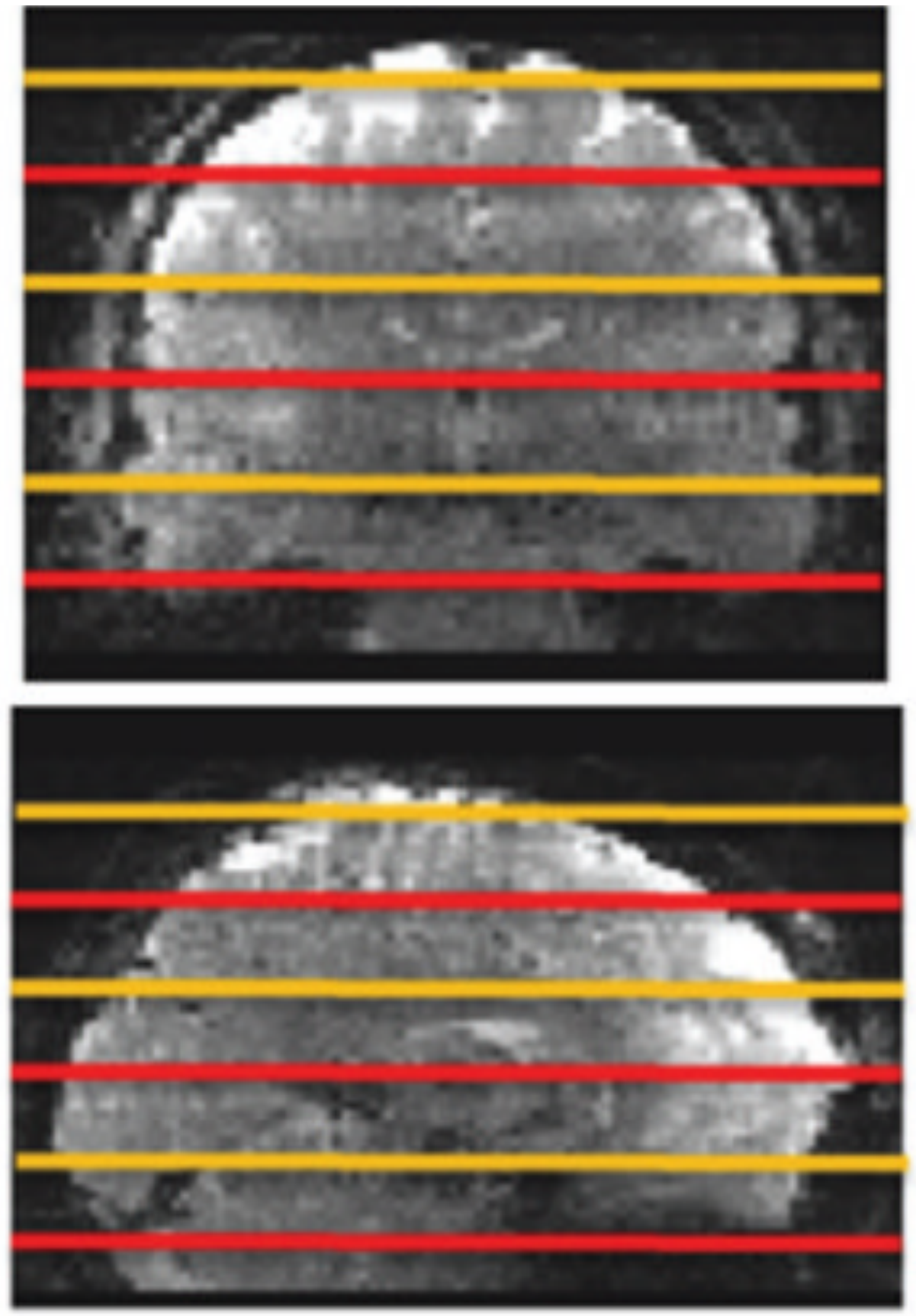
Ciric et al (2017)

Preprocessing advice
预处理建议

- Read up on the latest literature 阅读最新文献
- Nuisance regression is not enough 噪声回归是不够的
- Low-pass filtering is not enough & often not necessary when using other approaches 低通滤波是不够的，在使用其他方法时通常不需要
- Use ICA-based methods and/or volume censoring
  使用基于ICA的方法和/或全脑检查
- Use physiological noise regression when interested in brainstem or other vulnerable brain regions 当对脑干或其他敏感的大脑区域感兴趣时，使用生理噪声回归
- Don’t use global signal regression 不要回归全脑信号

Data acquisition advice
数据采集建议

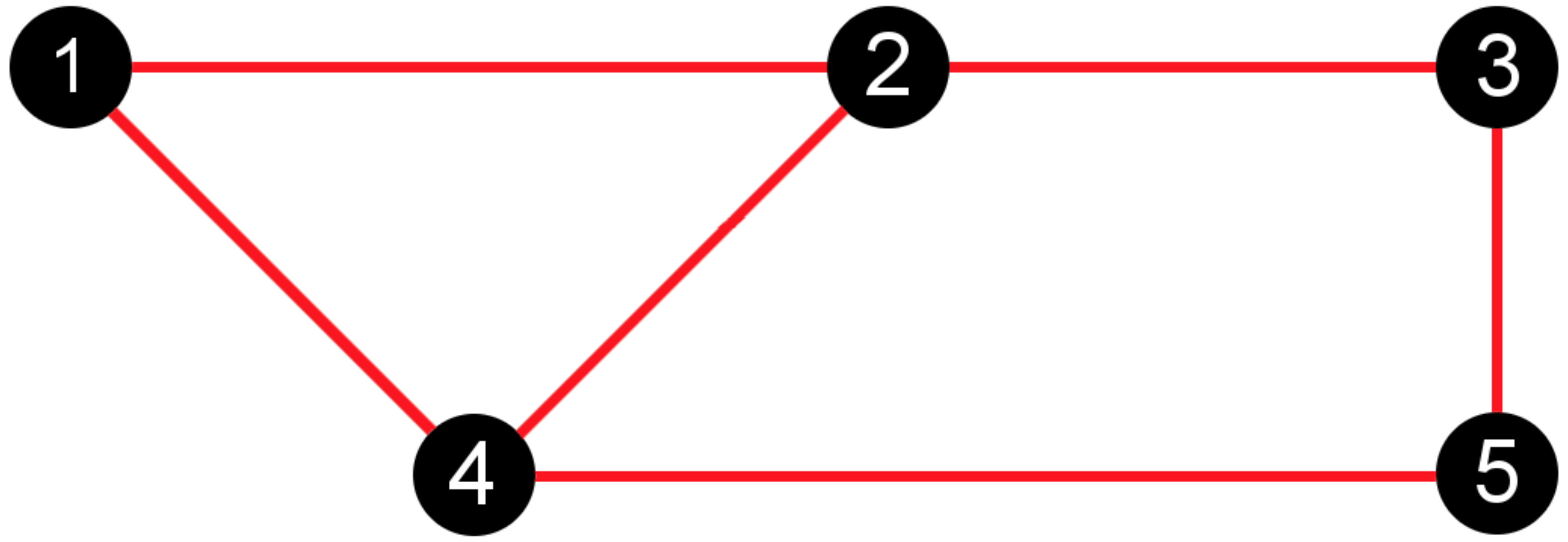
- Just a guide, may vary depending on study aims!
  只是一个建议，可能会根据研究目标而有所不同！
- Whole brain coverage, voxelsize: 2 - 3 mm
  全脑覆盖，体素大小：2-3毫米
- Scan duration: 扫描持续时间
  - 10-15 minutes per scan 每次扫描10-15分钟
  - Potentially multiple scans 可以多次扫描
- Repetition time: ideally close to 1 second (multiband/multiplexed imaging) 重复时间：理想情况下接近1秒（多频段/多路复用成像）
- Paradigm: eyes open, fixation cross 范式：睁眼，固定十字架
- Auxiliary data: physiology, sleep 辅助数据：生理，睡眠



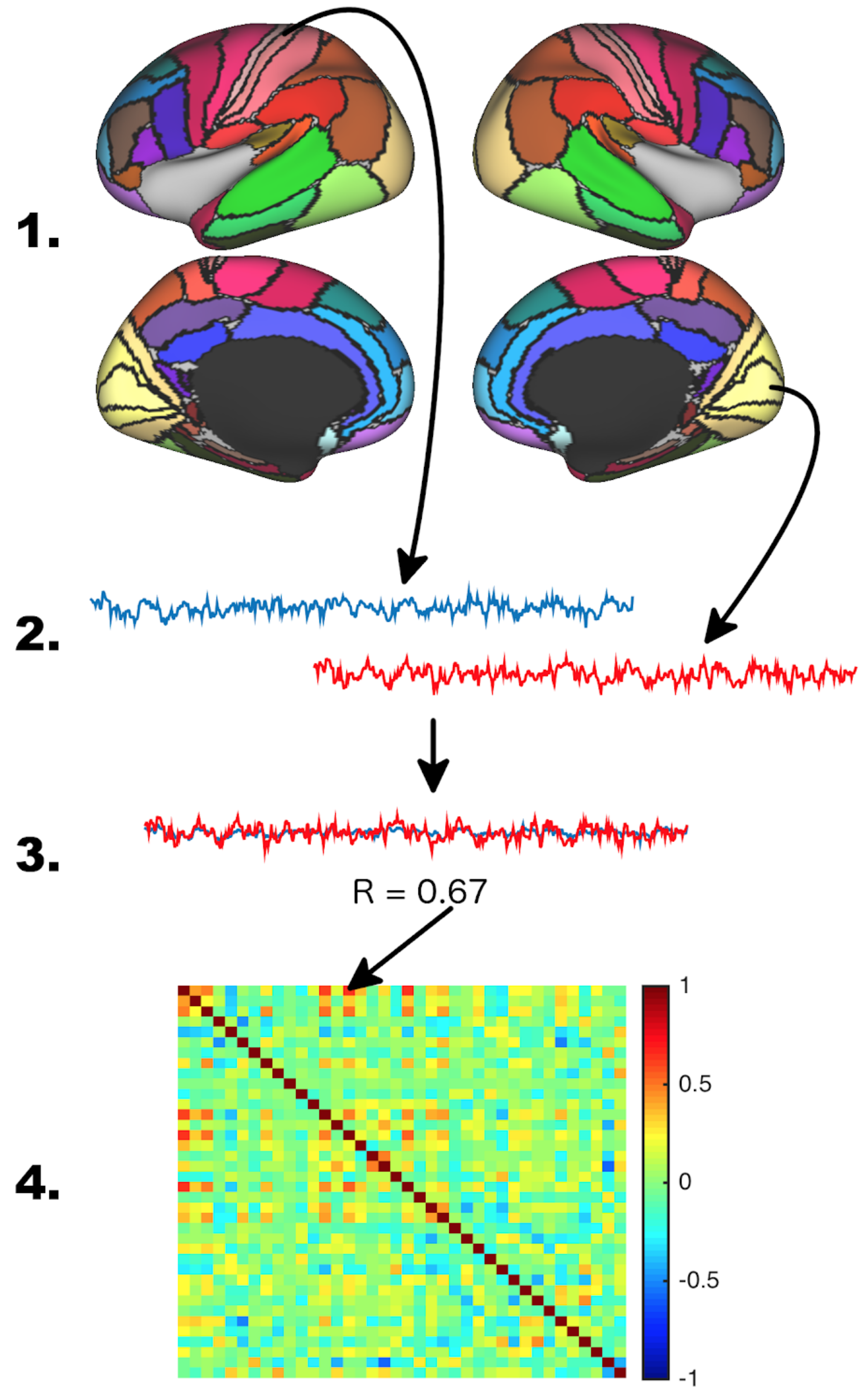
Network modelling analysis
网络建模分析

Glossary
词汇表

- Node = functional brain region 节点=功能性大脑区域
  - Contiguous nodes = interconnected ‘blobs’ 连续节点=互连’节点'
  - Non-contiguous nodes = e.g. bilateral 非连续节点=例如双边
- Parcellation = separation of all voxels into a set of nodes
- 分区 = 将所有体素分离为一组节点
  - Hard parcellation = binary regions 二进制区域
  - Soft parcellation = weighted regions 加权区域
- Edge = connection between nodes 边缘=节点之间的连接
- Connectomics = mapping all connections between all brain regions
  连接组 = 映射所有大脑区域之间的所有连接



Analysis steps
分析步骤



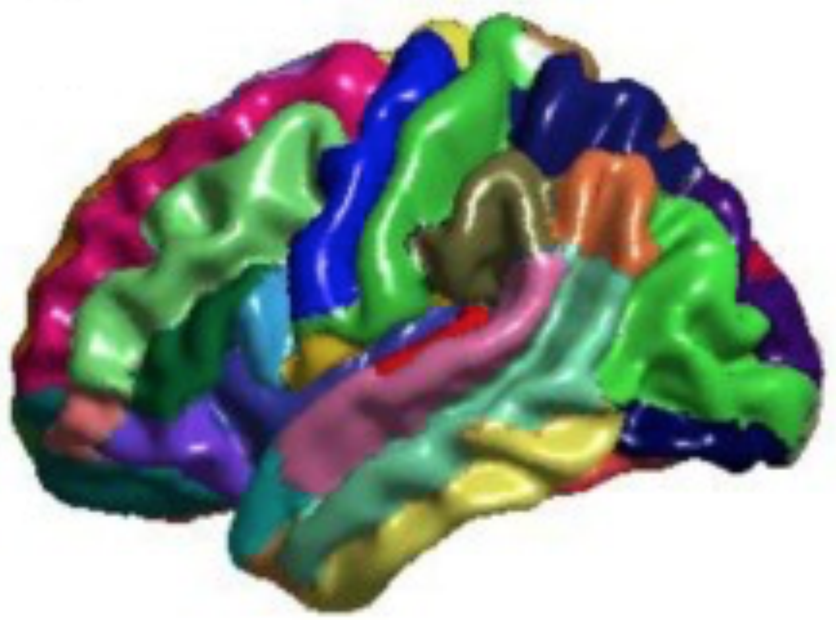
- Node definition 节点定义
- Timeseries extraction 时间序列提取
- Edge calculation 边缘计算
- Network matrix 网络矩阵
- Group analysis 组分析

Node definition

节点定义

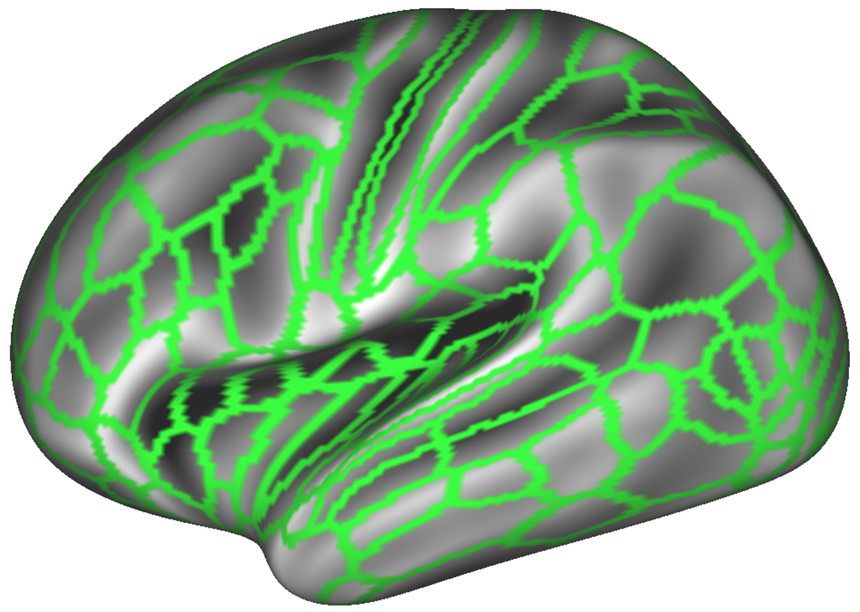
Anatomical atlases

结构模板



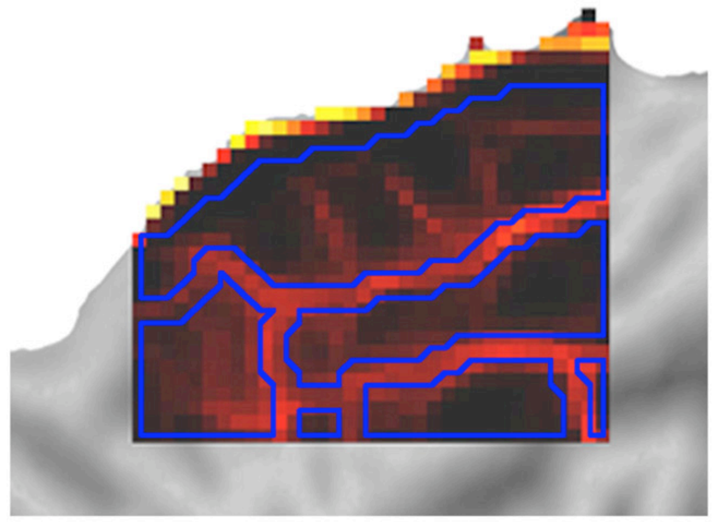
Functional atlases

功能模板



Data-driven parcellation

数据驱动分区



Tzourio-Mazoyer et al (2002), Yeo et al (2011), Glasser et al (2016), Cohen et al (2009)

Node definition

节点定义

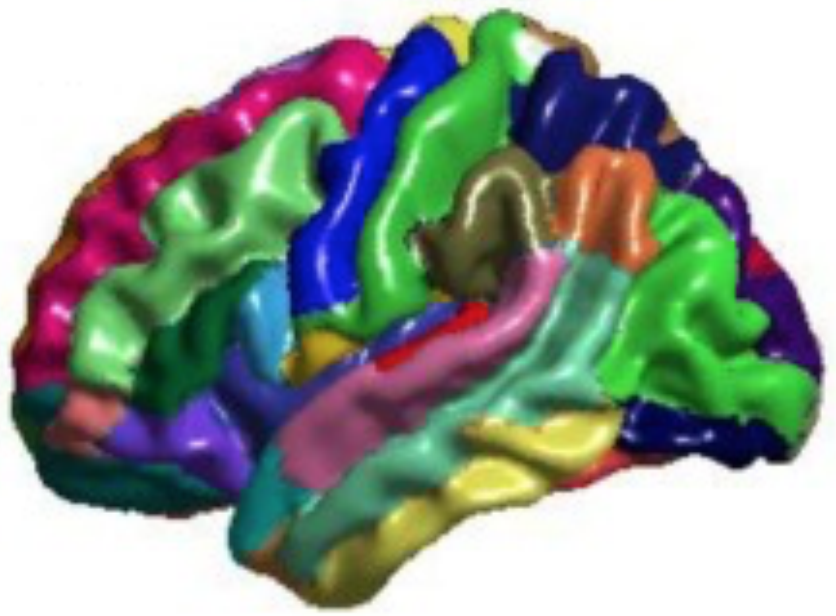
<u>Anatomical atlases</u> | <u>Functional atlases</u> | <u>Data-driven parcellation</u>

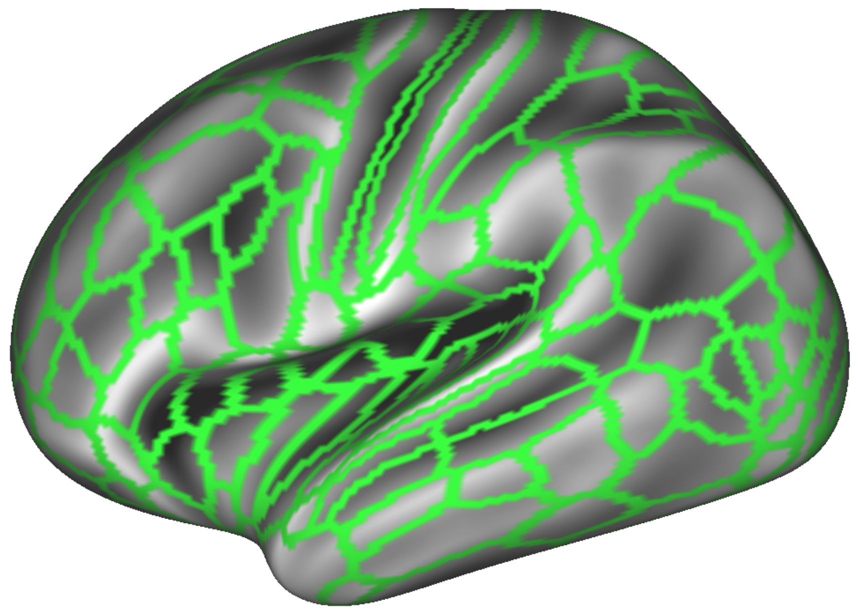
- Harvard-Oxford/ AAL

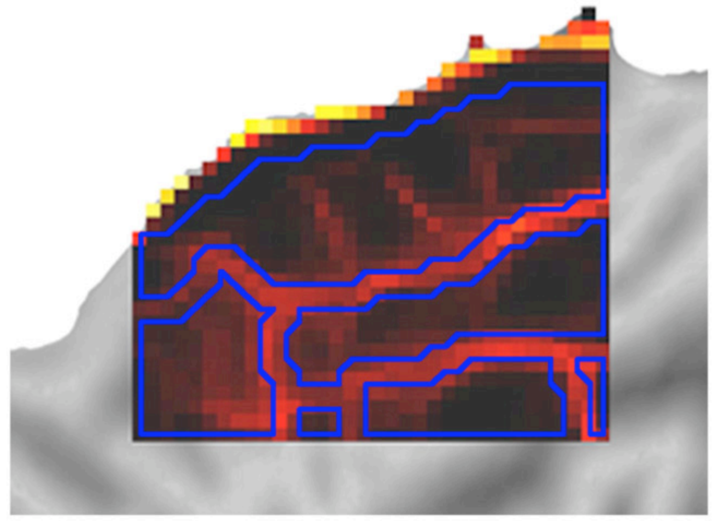
  哈佛/AAL

- Avoid if possible because typically based on small number of subjects and not a good estimation of functional boundaries

尽可能避免，因为通常基于少量被试，对功能边界不能良好的估计







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Node definition

节点定义

Anatomical atlases	Functional atlases	Data-driven parcellation

Anatomical atlases

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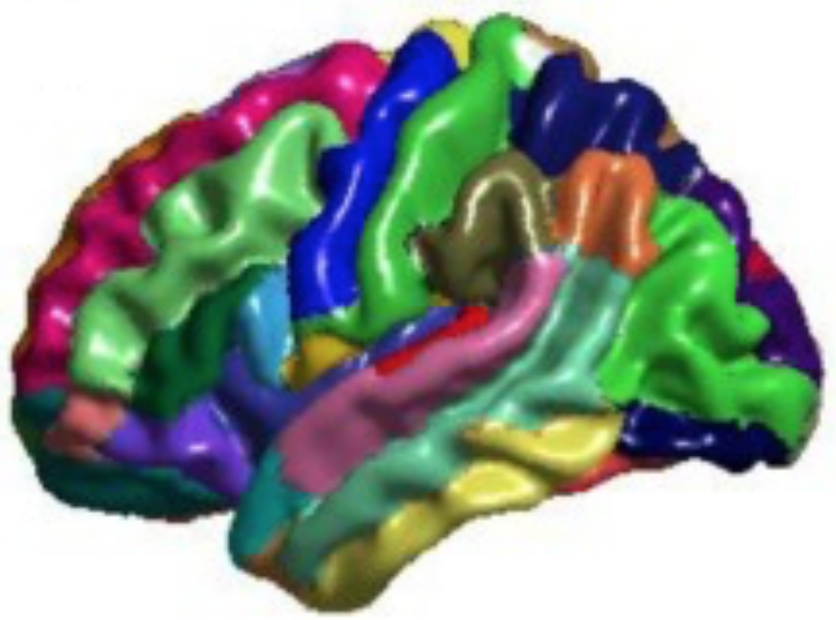
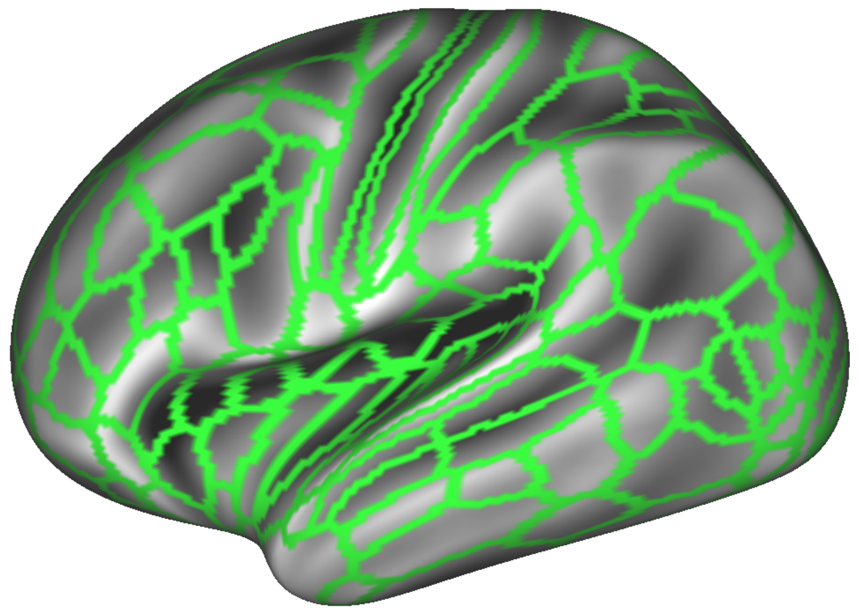


Functional atlases

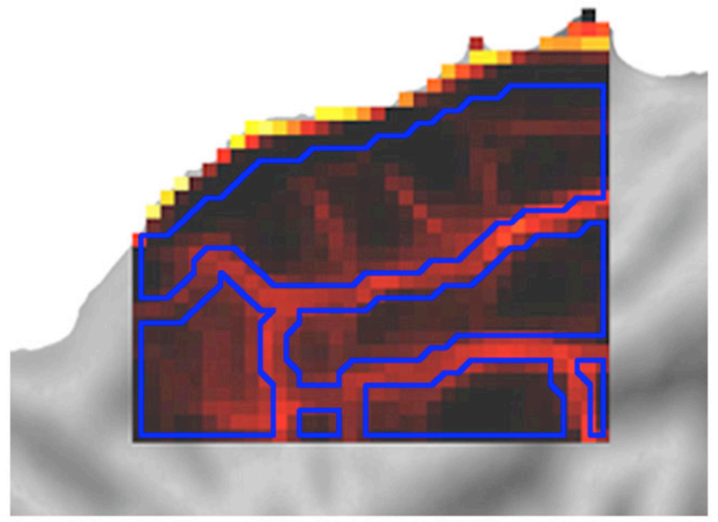
- Yeo 2011/ Glasser 2016
- Many good functional atlases available, though few comparison studies
- How to map onto individuals is very important



Data-driven parcellation

虽然很少有比较研究，但可以使用许多功能良好的模板

如何映射到个体空间是非常重要的



Tzourio-Mazoyer et al (2002), Yeo et al (2011), Glasser et al (2016), Cohen et al (2009)

Node definition

节点定义

Anatomical atlases

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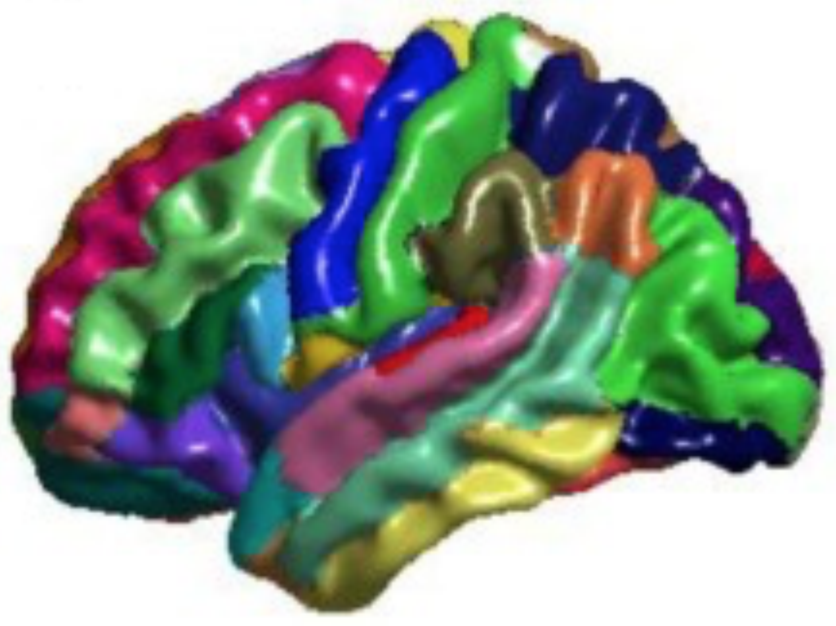

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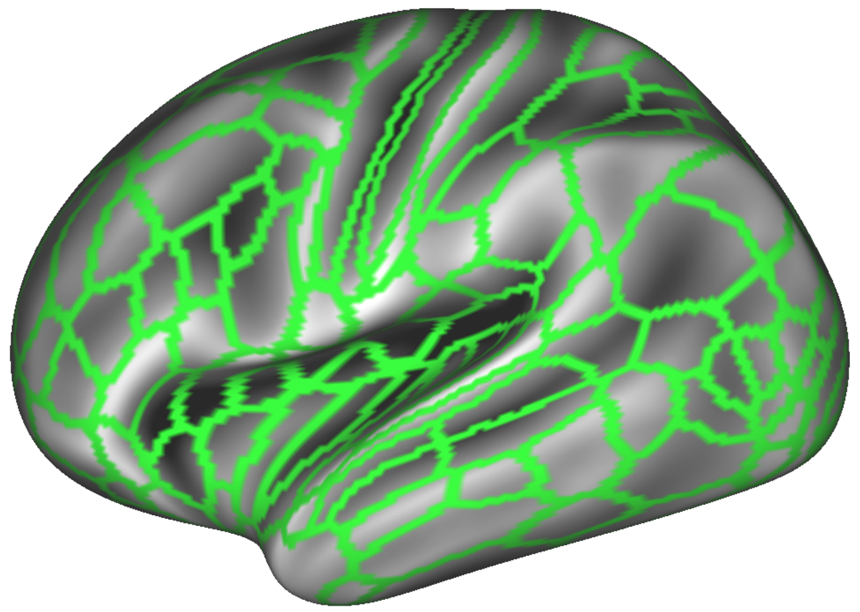
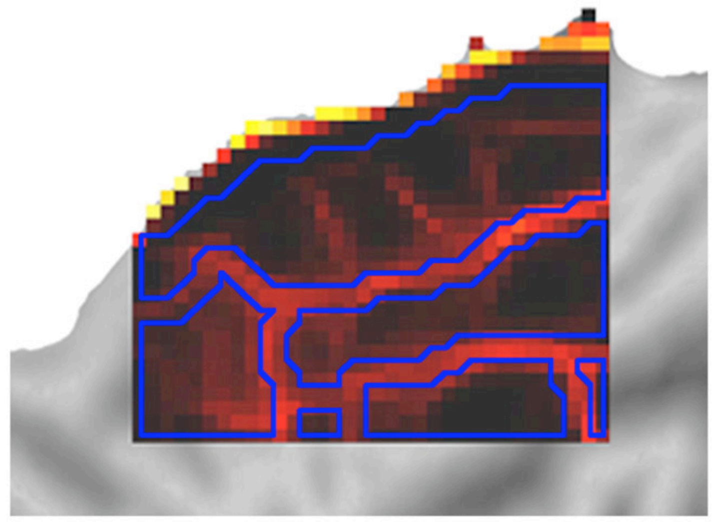


Data-driven parcellation

- ICA/ Clustering/ Gradients
- Estimate parcellation from the same dataset used for further analyses

  从用于进一步分析的相同数据集中估算分区
- How to map group parcellation onto individuals very important

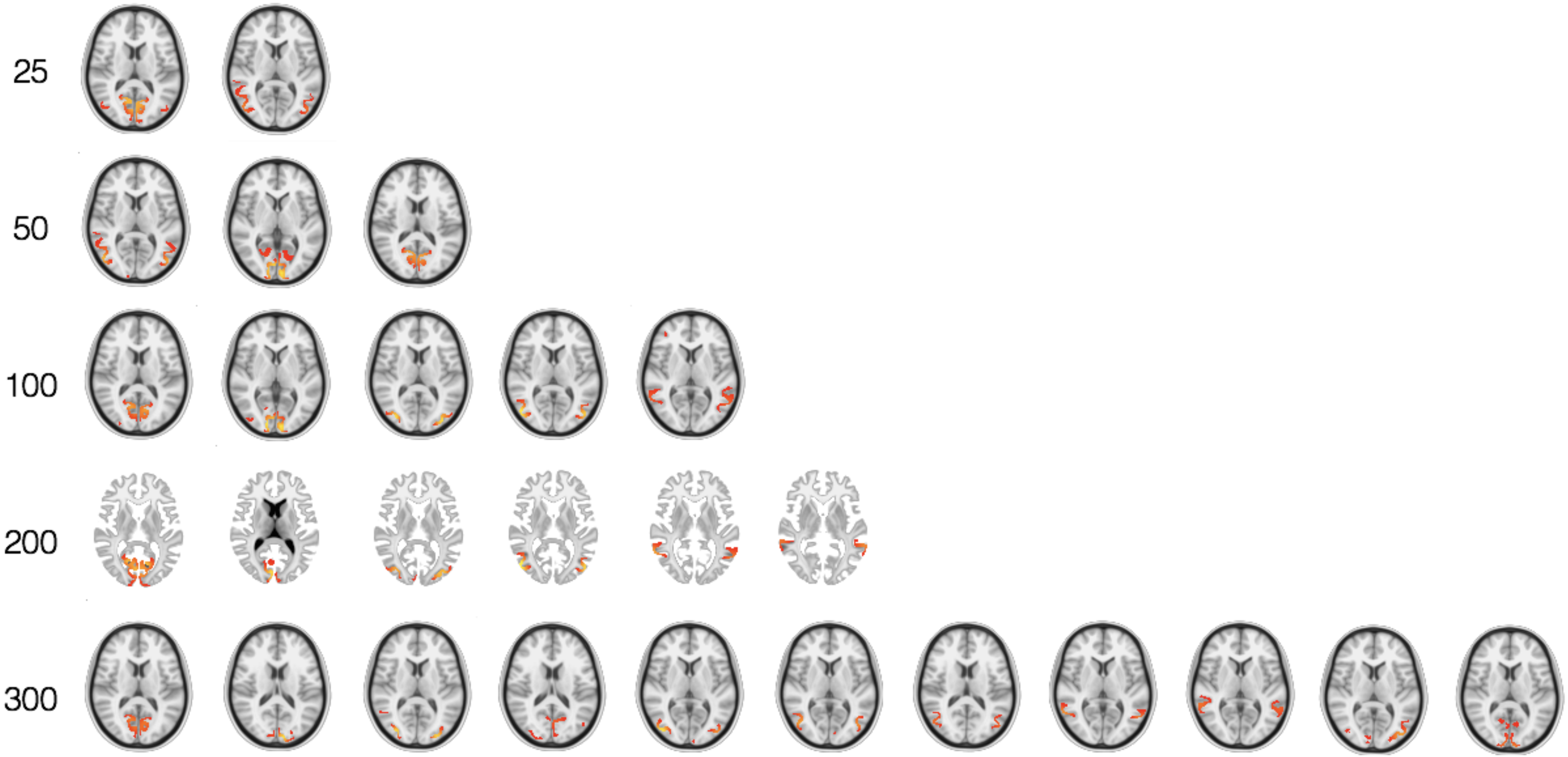
  如何将组分割映射到个体非常重要



Tzourio-Mazoyer et al (2002), Yeo et al (2011), Glasser et al (2016), Cohen et al (2009)

ICA for parcellation

ICA分区



Timeseries extraction
时间序列提取

<u>Hard parcellation:</u>

- Masking (mean timeseries) 掩板（平均时间序列）
- Eigen timeseries (PCA) 特征时间序列（PCA）
- Using multilayer classifier 使用多层分类器

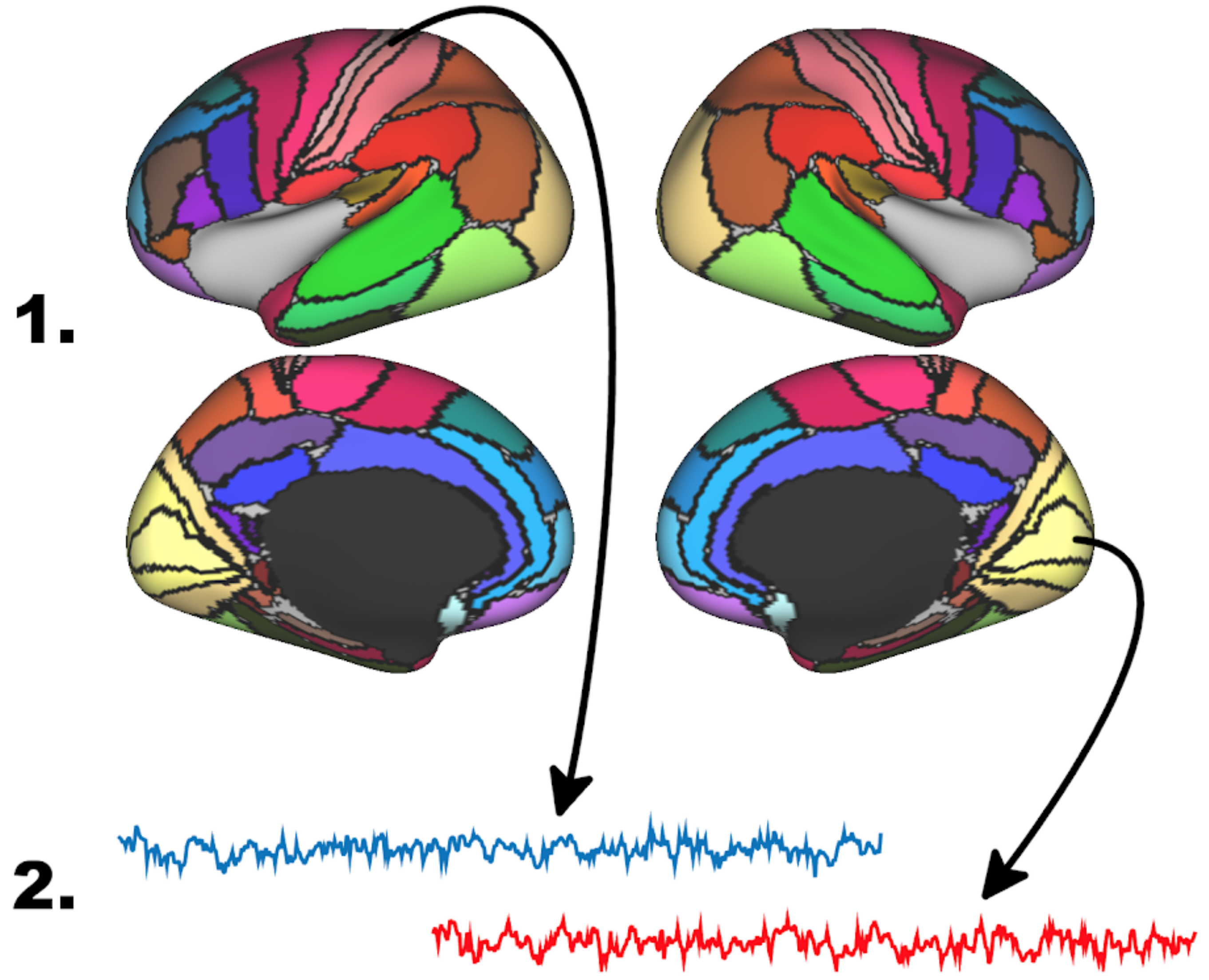
<u>ICA (soft parcellation):</u>

- **Thresholded** dual regression/ back projection

  阈值双重回归/反投影

<u>Alternative:</u> 其他

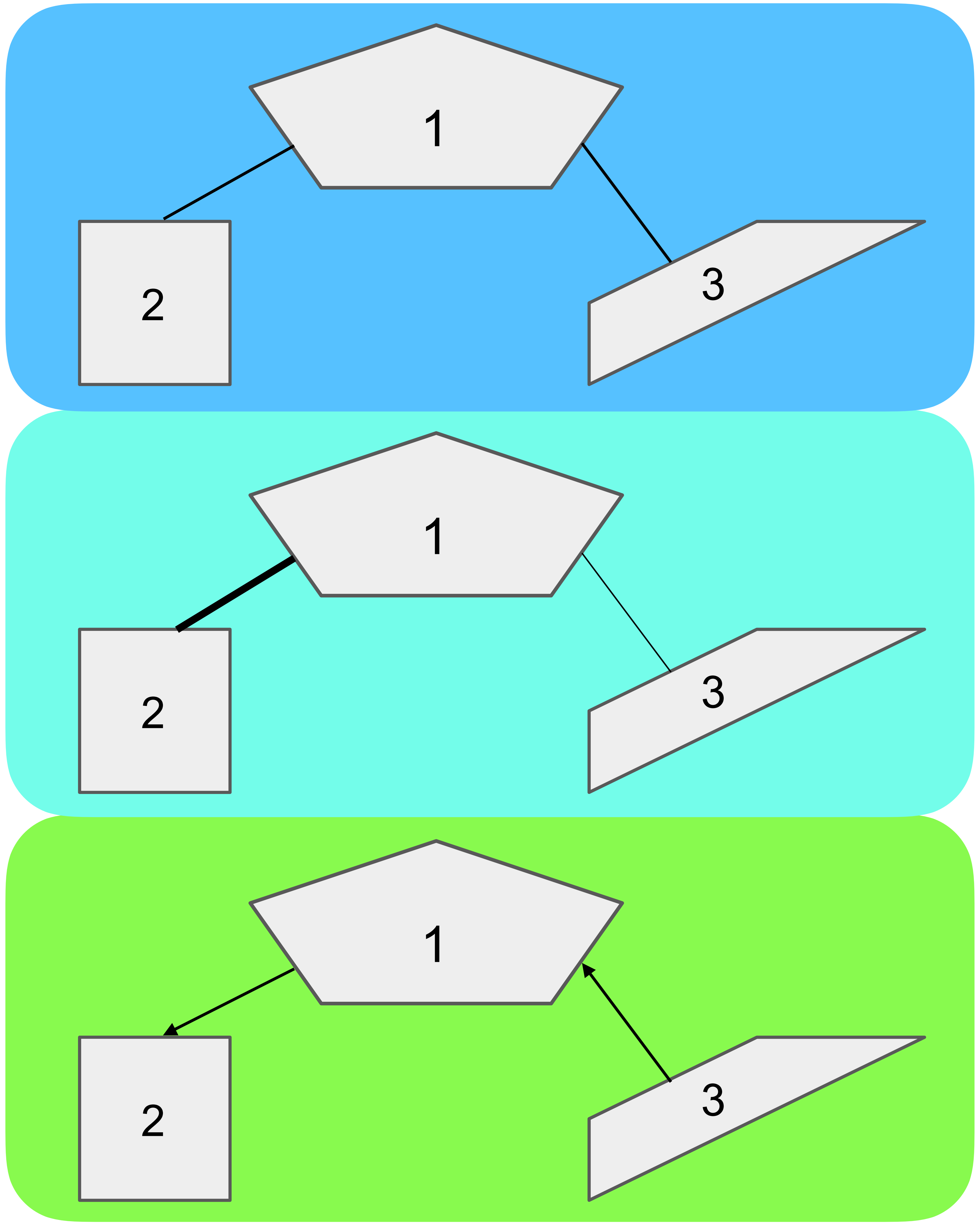
- Hierarchical estimation of group & subject 组、个体的分层估计
- e.g. PROFUMO



Hacker et al (2013) , Fillippini et al (2009), Calhoun et al (2001), Harrison et al (2015), Bijsterbosch et al (2019)

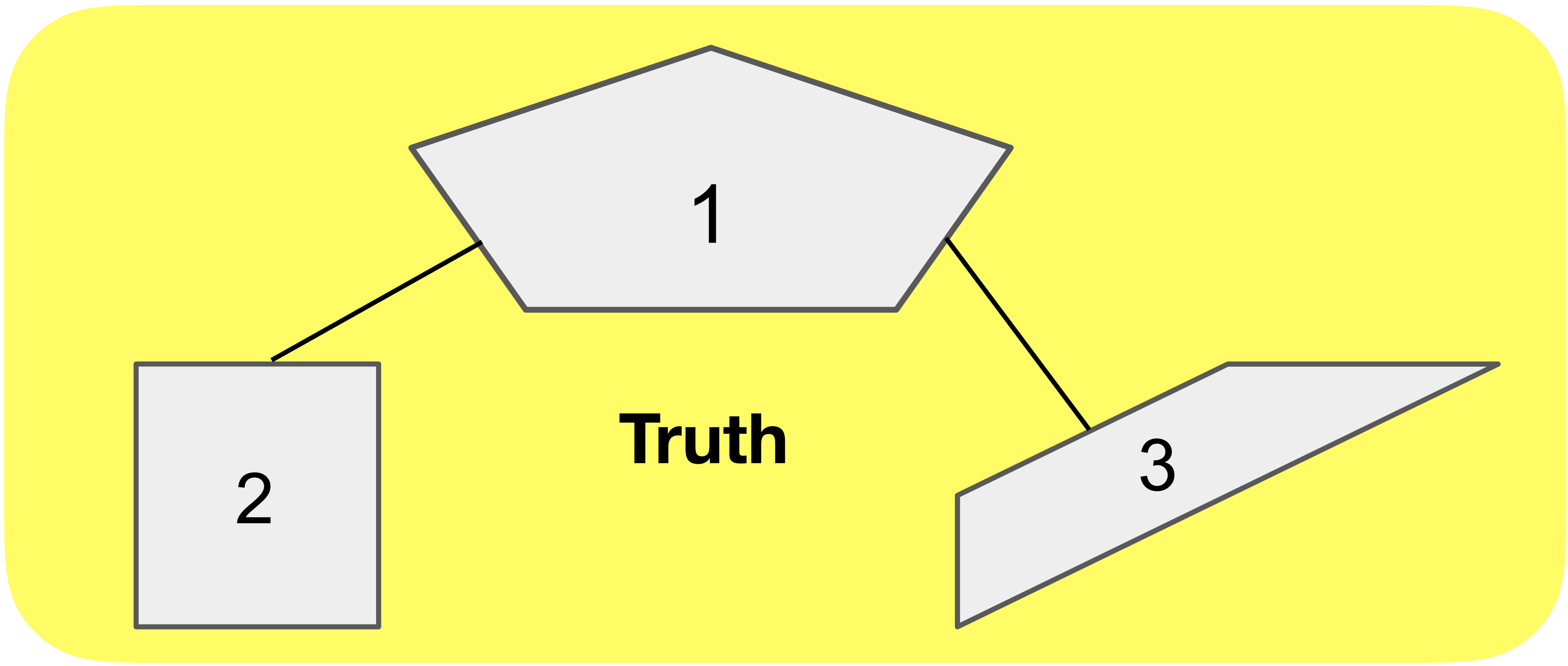
Edge calculation
边缘计算

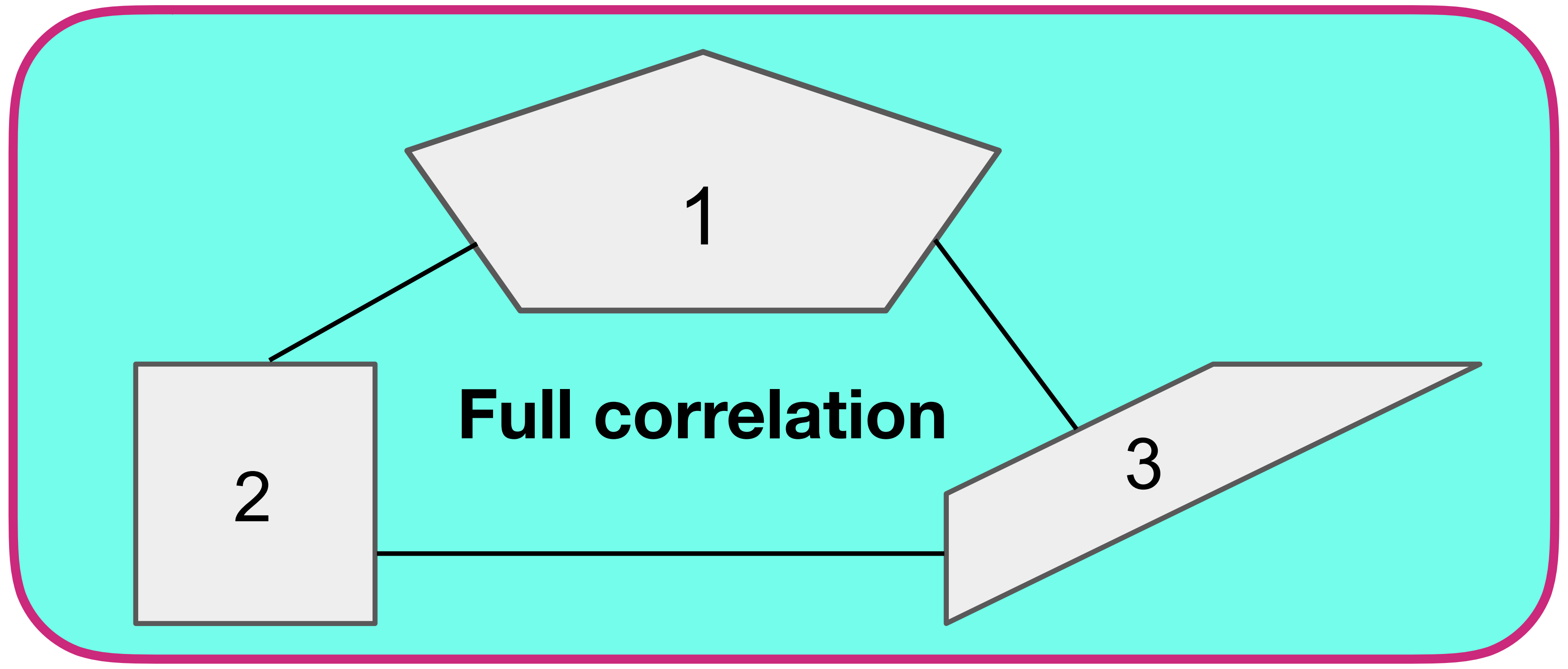
- Presence/ absence of edges 存在/不存在边缘
- Strength of edges 边缘强度
- Directionality of edges 边缘的方向性



Direct versus indirect connections
直接连接与间接连接

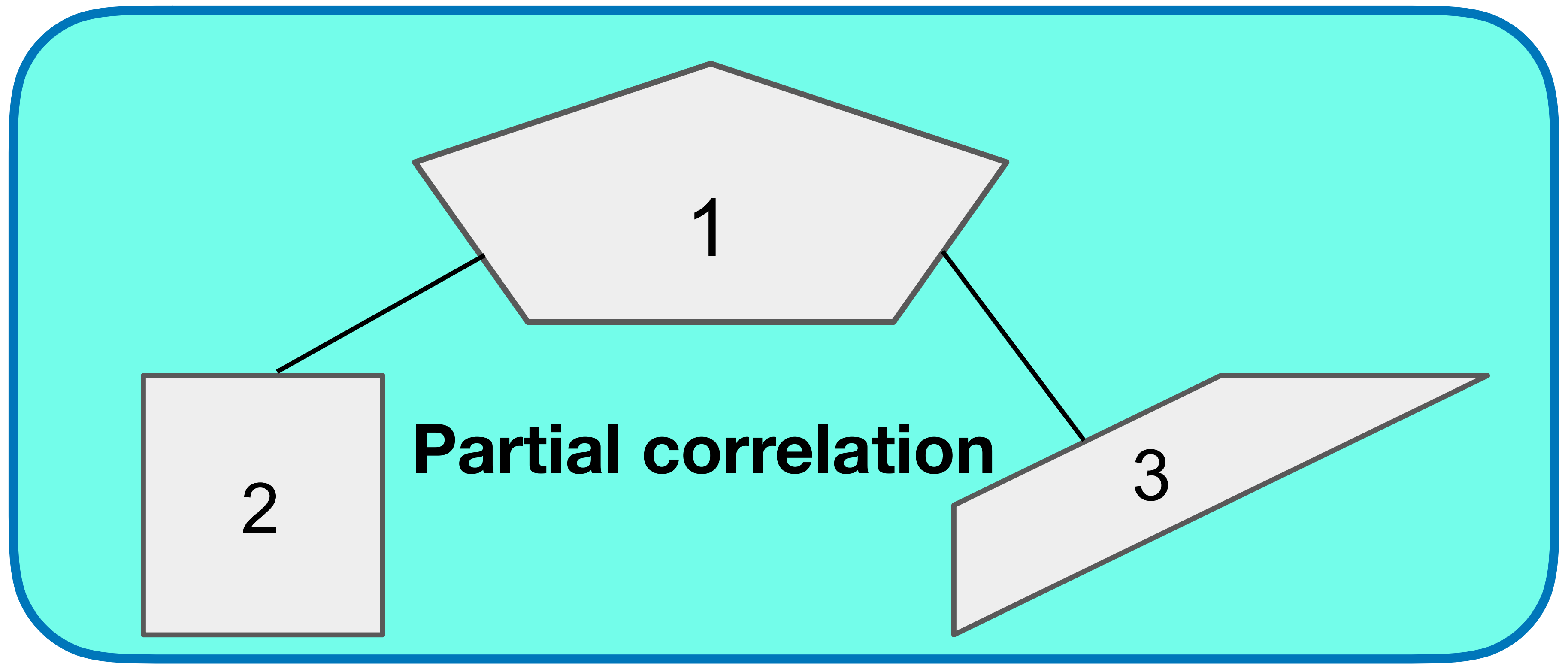
- Correlation between 2 and 3 will exist
  2和3之间存在相关性
- Therefore full correlation will incorrectly estimate connection 2-3
  因此，完全相关将错误地估计连接2-3
- 2-3 is an indirect connection
  2-3是间接连接

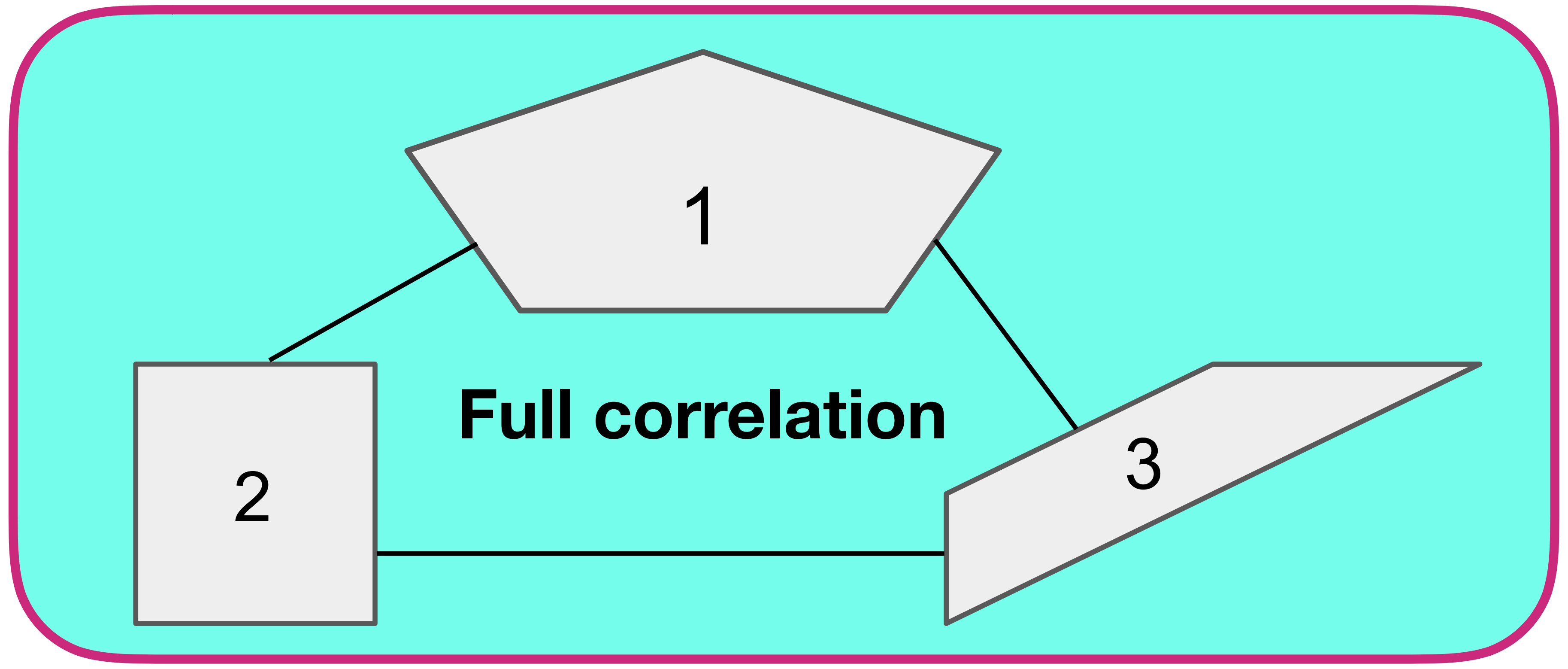




Partial correlation
偏相关

- Before correlating 2 and 3, first regress 1 out of both (“orthogonalise wrt 1”) 在关联2和3之前，首先从两者中回归1（“正交wrt 1”）
  - If 2 and 3 are still correlated, a direct connection exists 如果2和3仍然相关，则存在直接连接
- More generally, first regress all other nodes’ timecourses out of the pair in question 更一般地说，首先从所讨论的对组中回归所有其他节点的时间序列
  - Equivalent to the inverse covariance matrix 等效于逆协方差矩阵



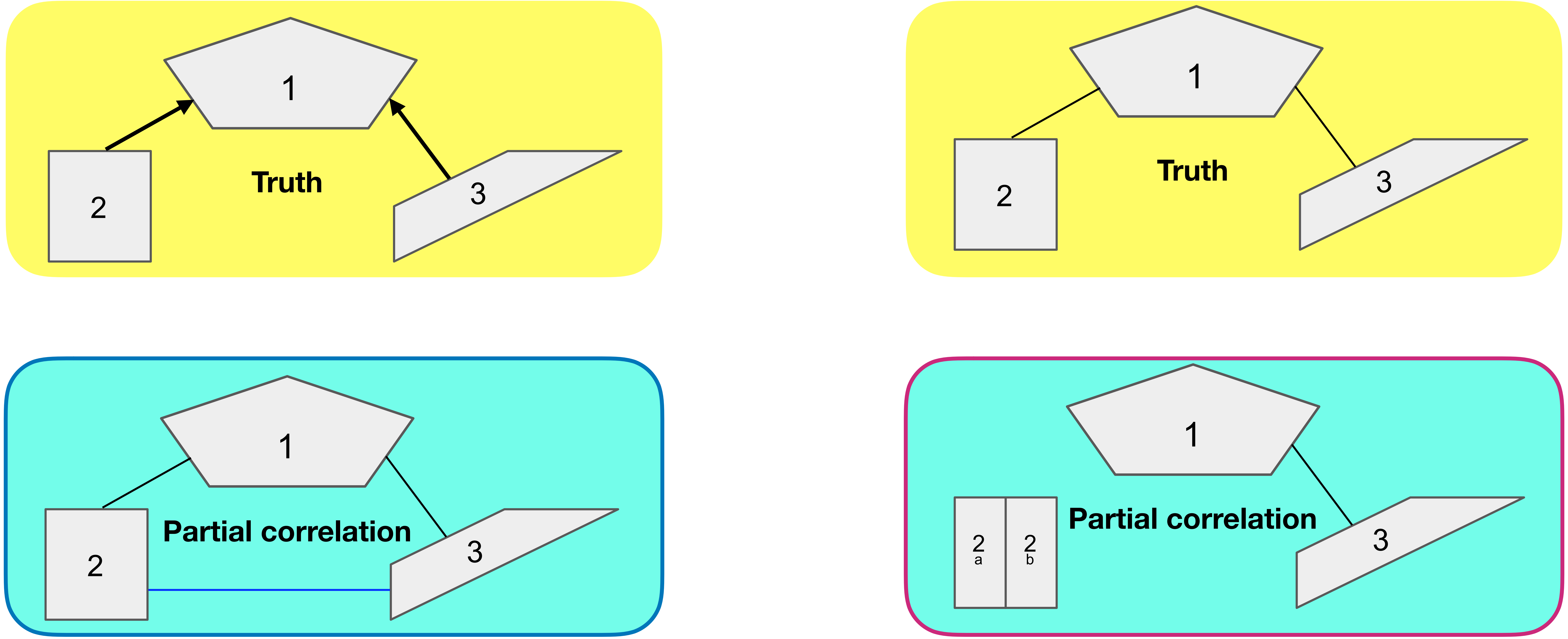


Regularisation
正规化

- Urgh! If you have 200 nodes and 100 timepoints, this is impossible!Urgh!
  如果你有200个节点和100个时间点，这是不可能的！
- A problem of DoF - need large #timepoints - #nodes DoF的问题 - 需要大的#时间点 - #节点
- When inverting a “rank-deficient” matrix it is common to aid this with some mathematical conditioning, e.g. force it to be sparse (force low values that are poorly estimated to zero)
  当反转“秩不足”矩阵时，通常用一些数学条件来辅助它，例如，强制它稀疏（强制估计为零的低值）
- Regularised partial correlation (such as ICOV, Ridge) 正则化的偏相关（如ICOV，Ridge）
- But still important to maximise temporal degrees of freedom 但是最大化时间自由度仍然很重要

Need to carefully define nodes

需要仔细定义节点



Berkson's paradox = false positive (2-3)

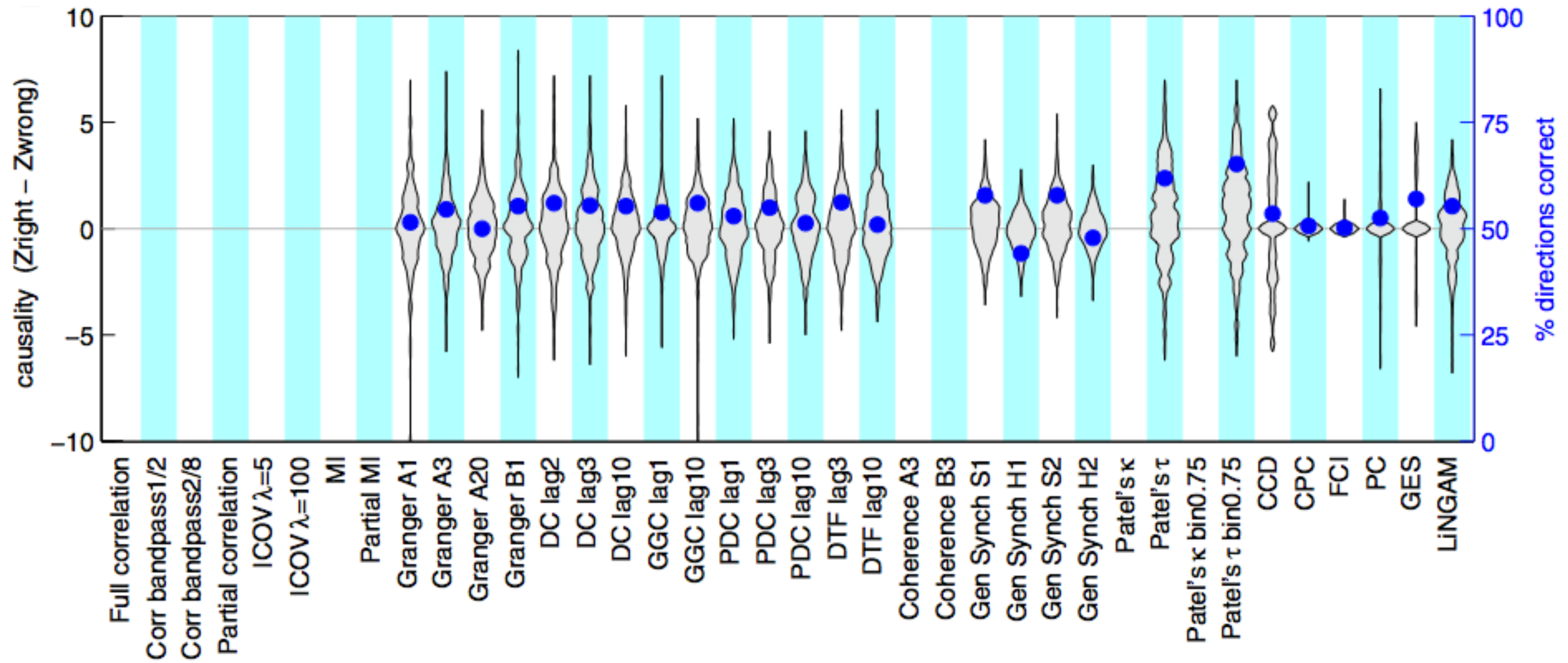
伯克森悖论=误报（2-3）

Over-splitting = false negative (1-2)

过度拆分=假阴性（1-2）

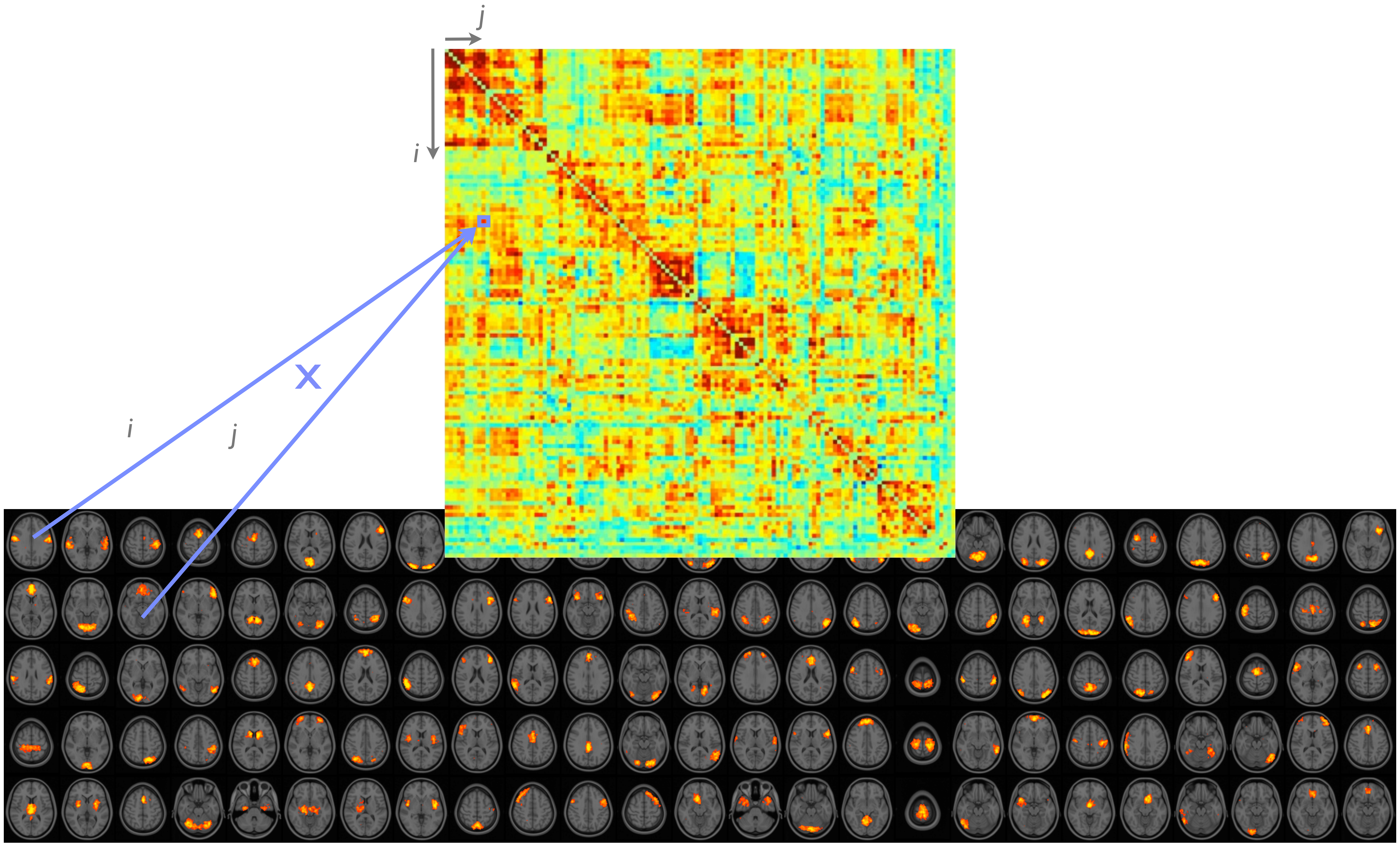
Directionality of edges
边缘的方向性

- Directionality is hard to estimate in BOLD data 在BOLD数据中难以估计方向性
- Don’t use lag-based methods such as Granger causality
  不要使用基于事后的方法，例如格兰杰因果关系
- Perhaps directionality is oversimplistic view of neural connectivity (particularly in resting-state)?
  也许方向性是神经连接过于简单的观点（特别是在静止状态下）？



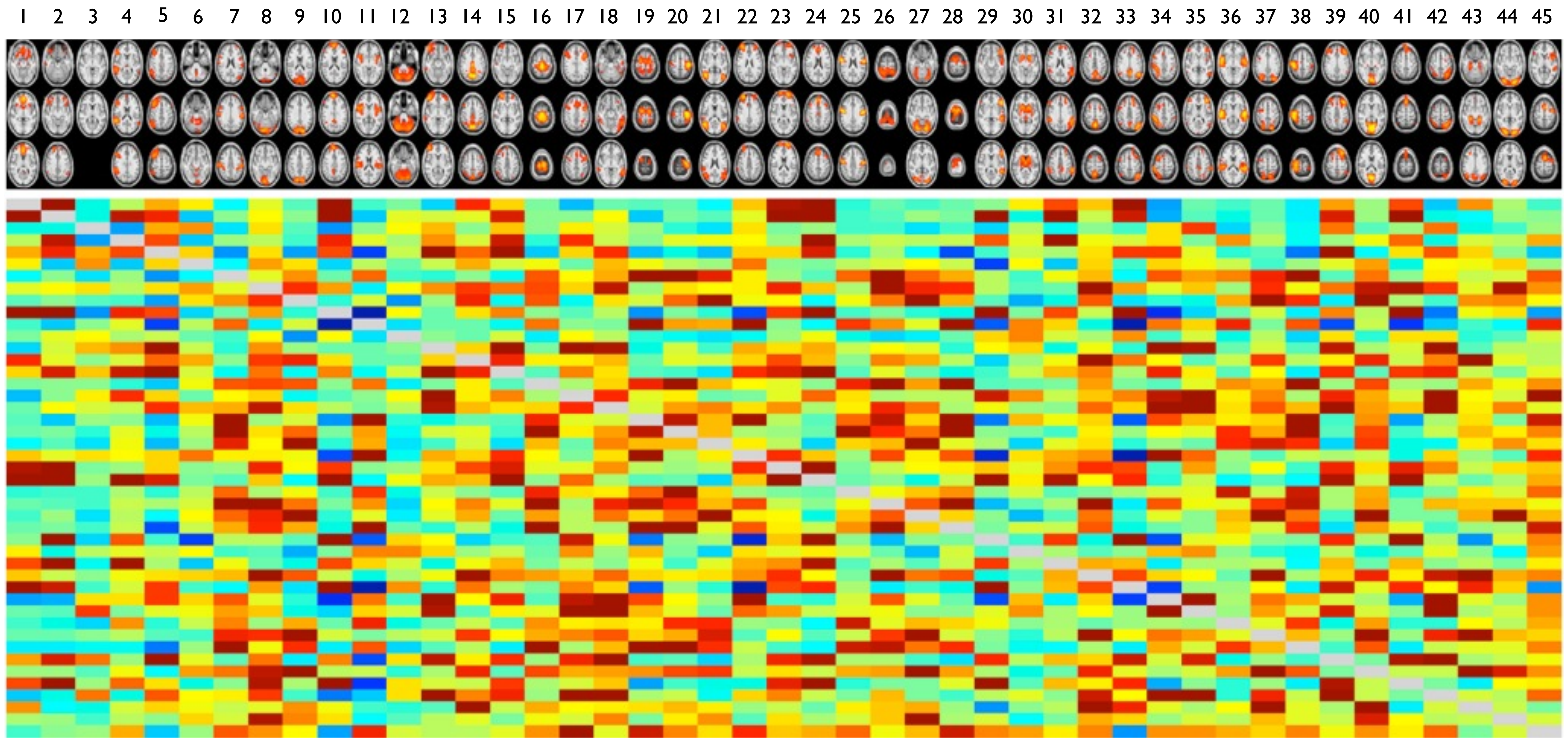
Smith et al (2011)

Building a network matrix
构建网络矩阵



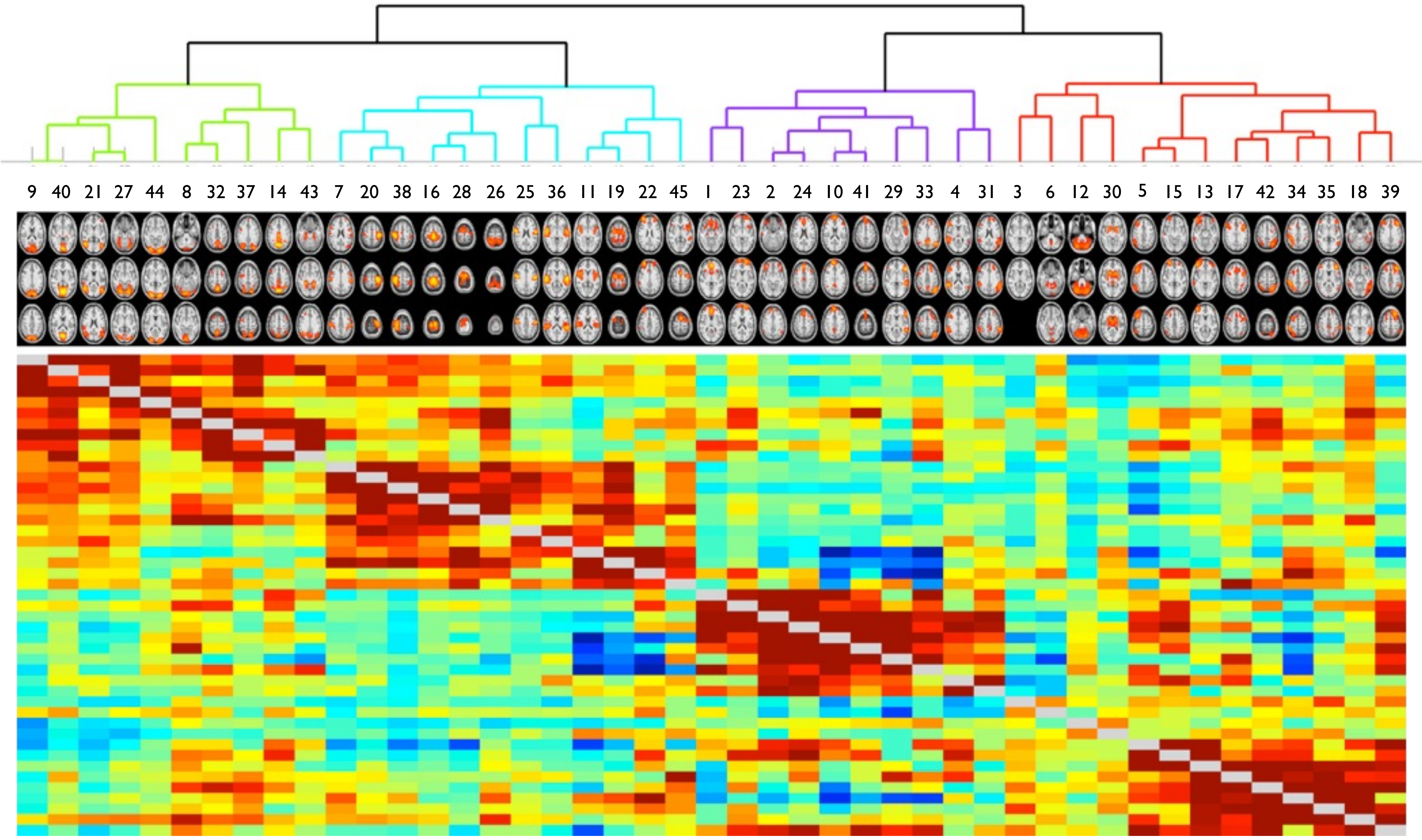
Network matrix

网络矩阵



Hierarchical clustering

分层聚类

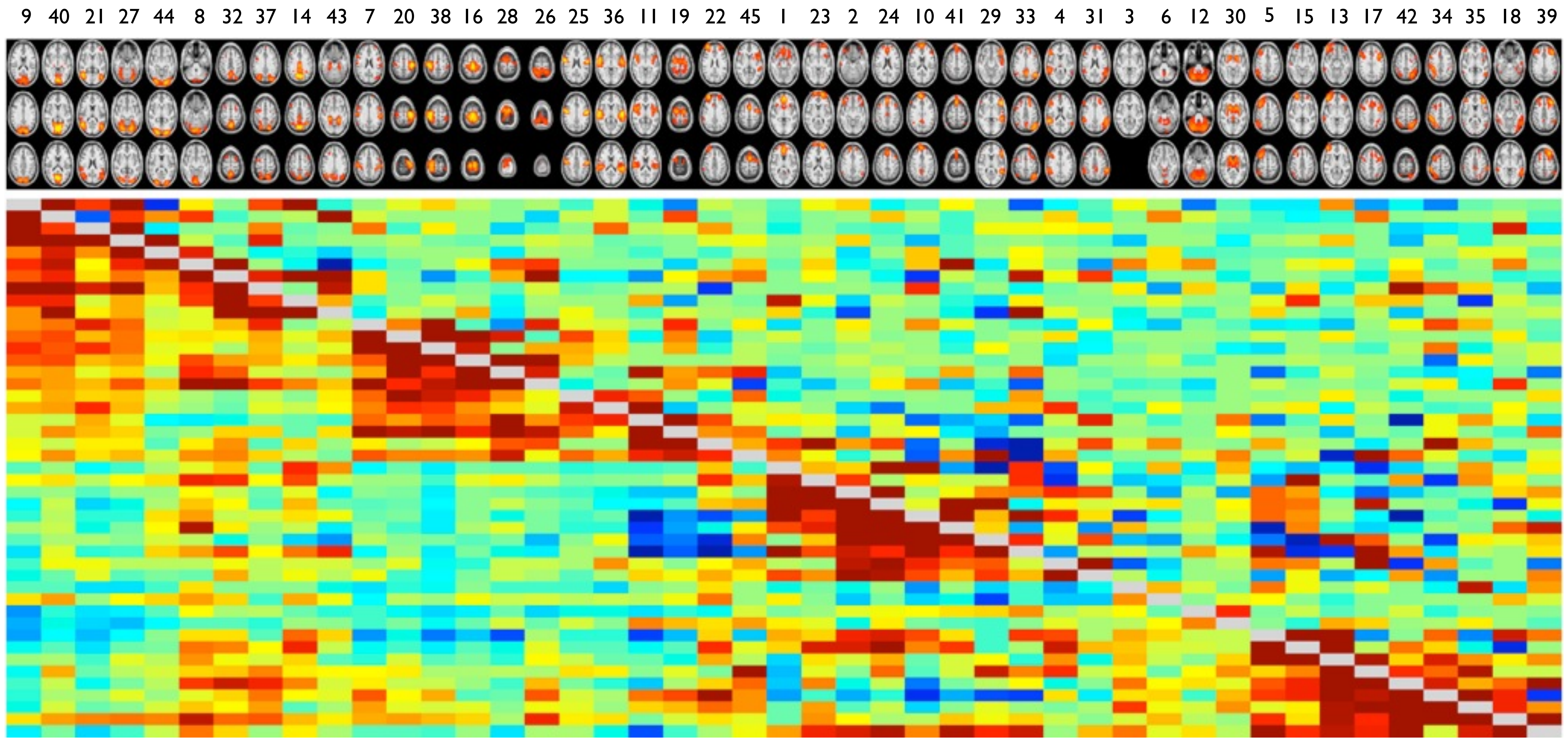


Partial correlation is sparser than full

部分相关比完全相关更少见

Full correlation matrix

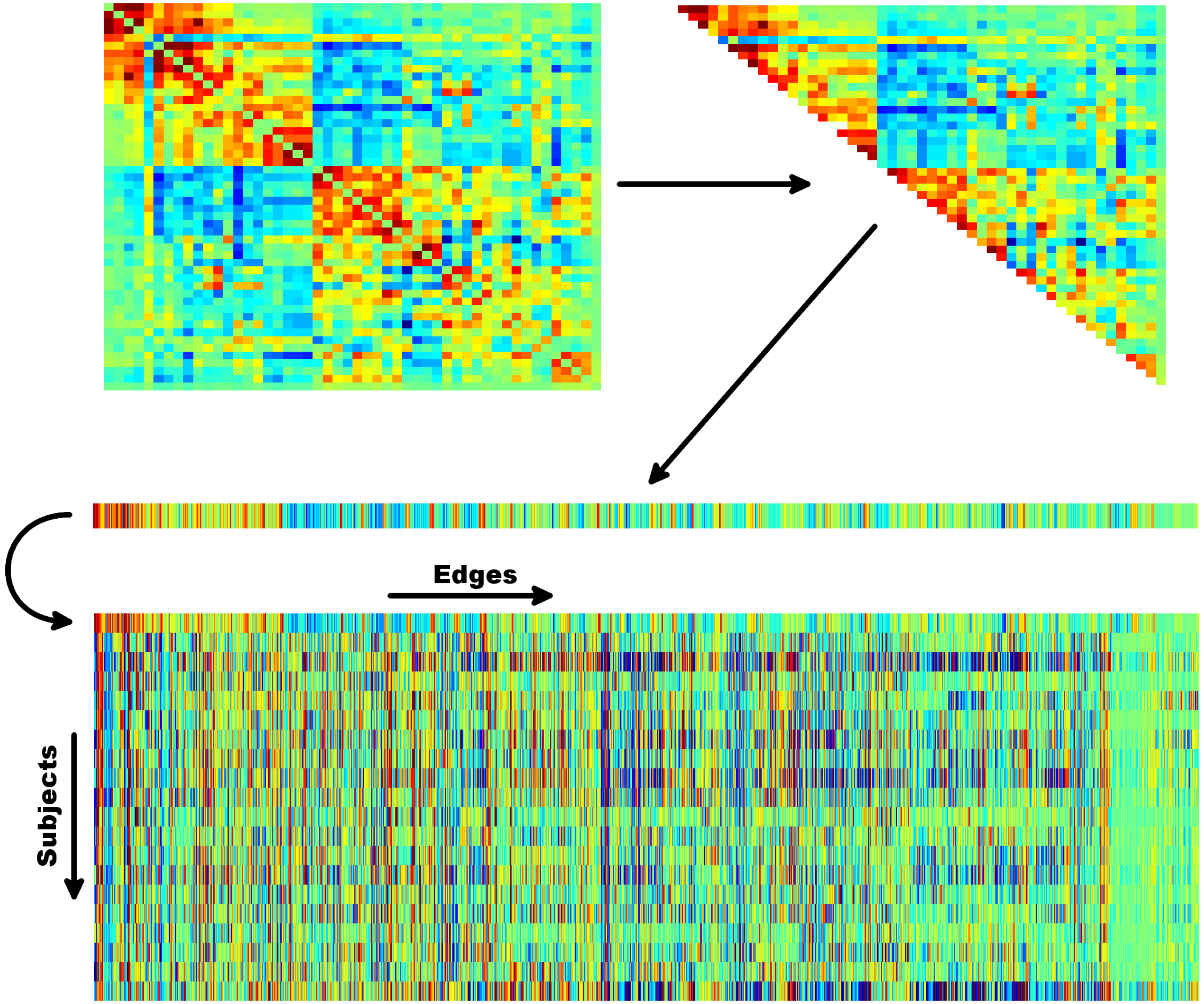
完全相关矩阵



Partial correlation matrix

偏相关矩阵

Group analysis
组分析



- Calculate network matrix for each subject 计算每个被试的网络矩阵
- Combine all network matrices into one 将所有网络矩阵合并为一个
- Perform group-level comparisons:组分析
    - Univariate tests for each edge (GLM) 每条边的单变量测试（GLM）
    - Multivariate prediction methods (SVM) 多变量预测方法（SVM）

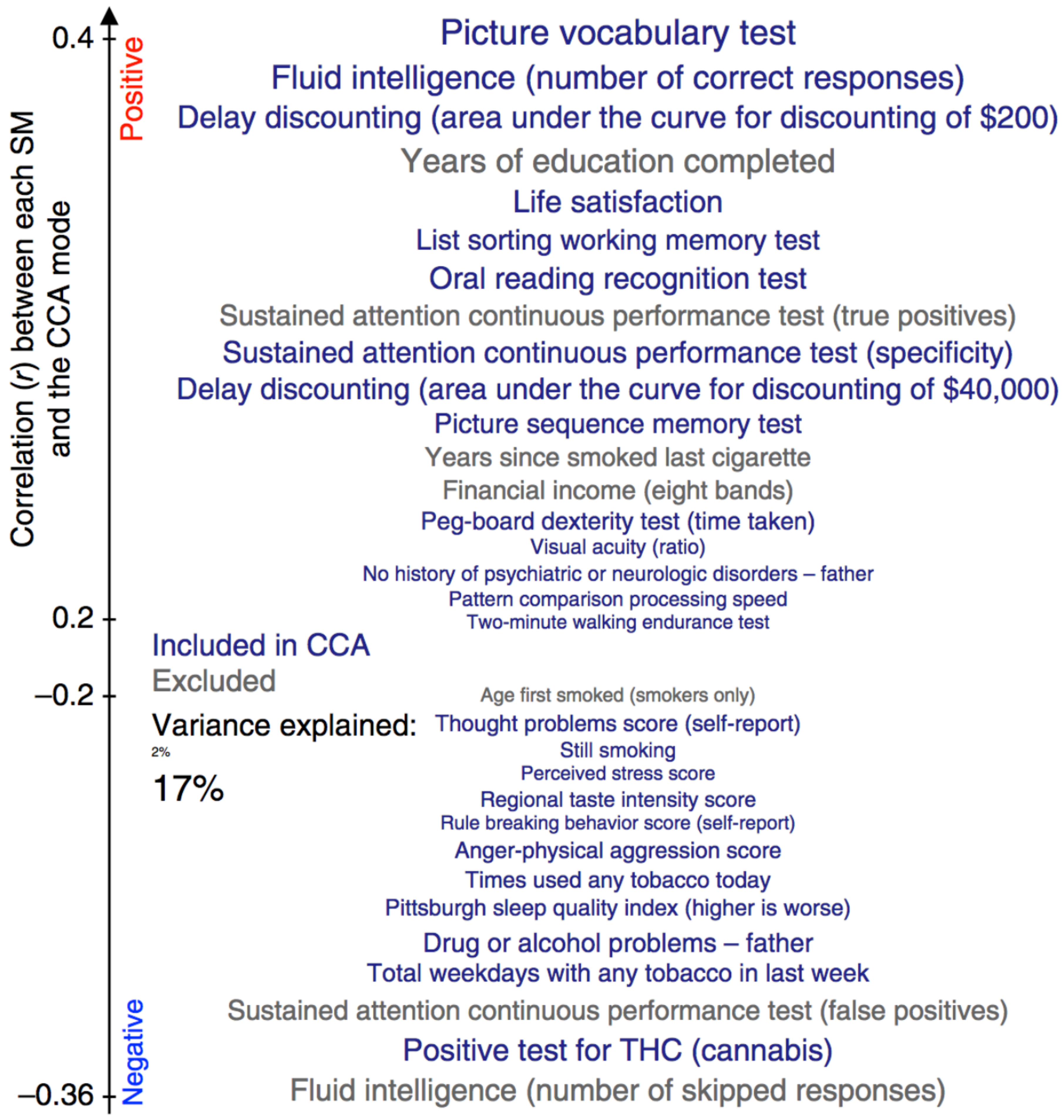
FSLnets

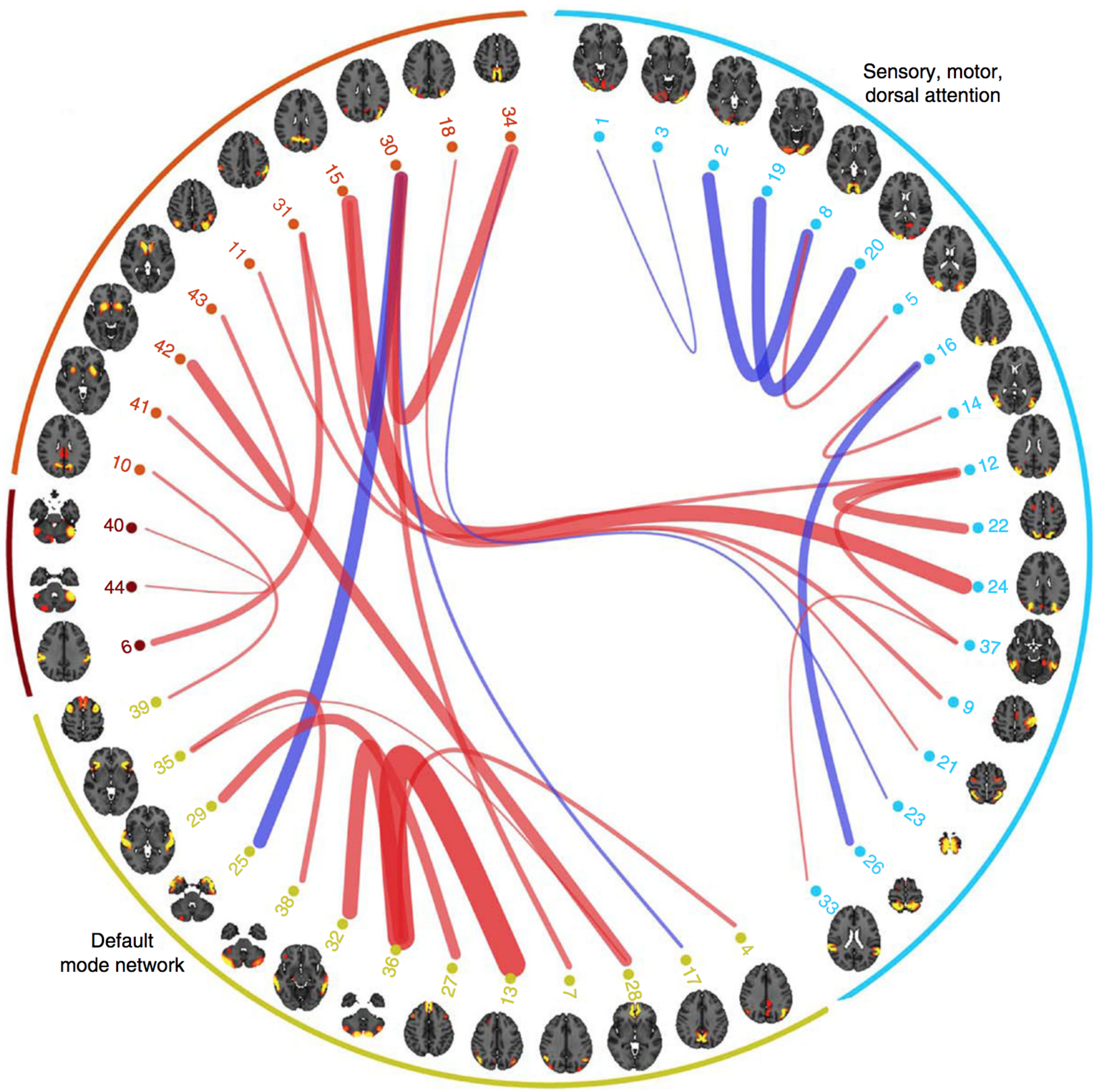
fsl网络分析

- Currently uses Matlab or Octave 目前使用Matlab或Octave
- Therefore this practical will be a bit different from other practicals 因此，这种分析方法与其他方法略有不同
- More information and download here: 更多信息及下载地址：https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FSLNets

Example: positive-negative mode

例如：正负模式

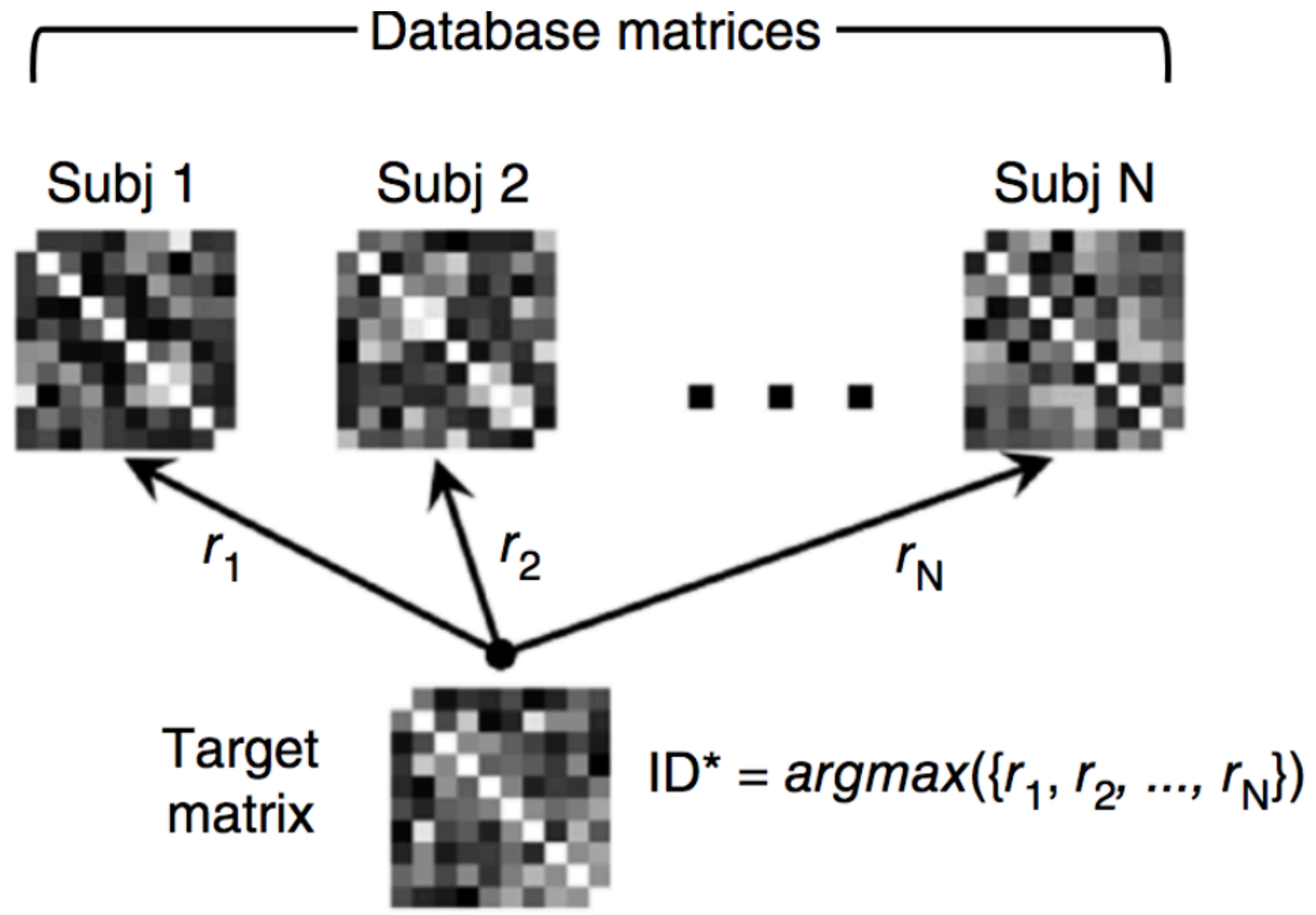


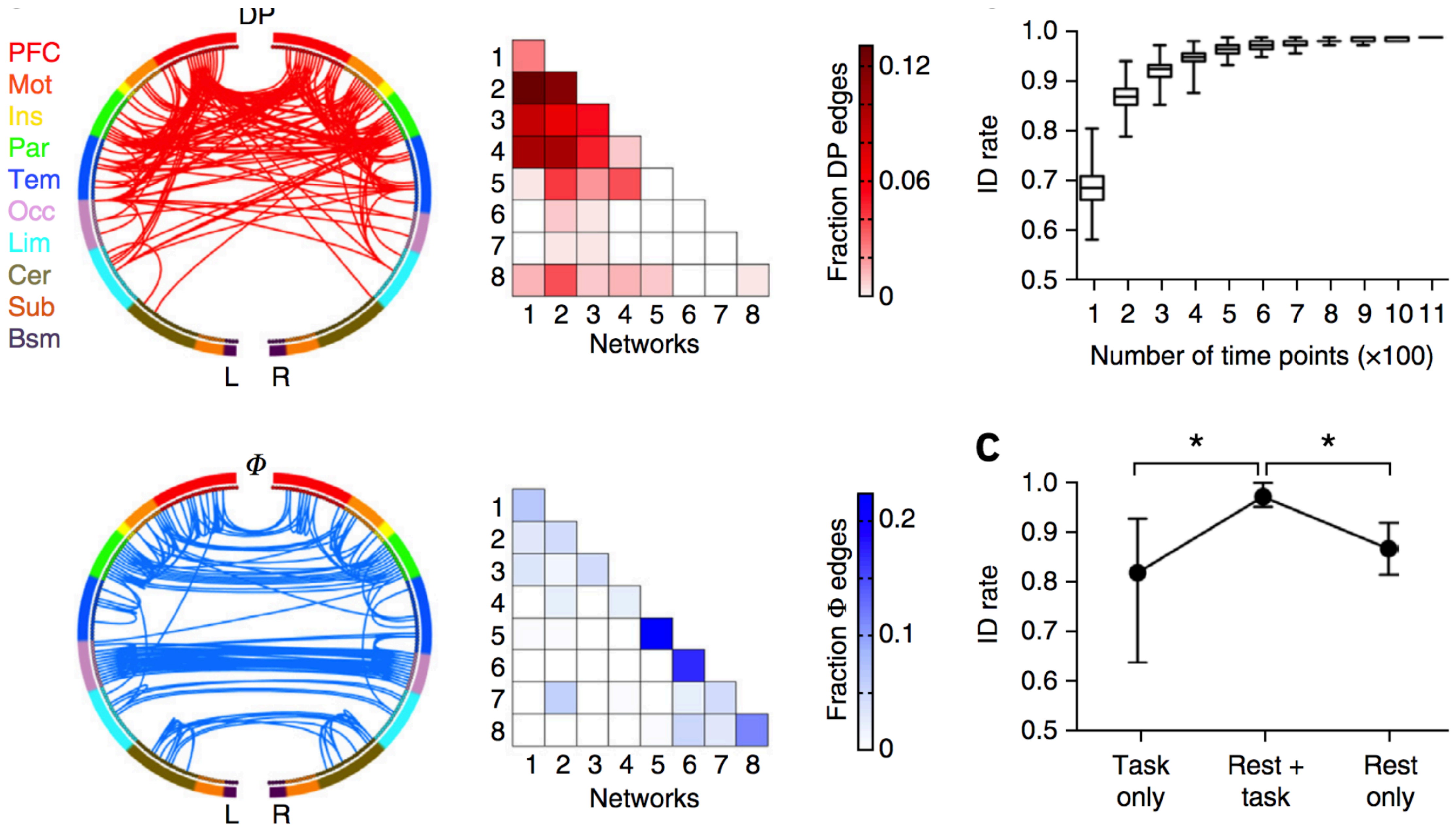


Smith et al (2015)

Example: connectivity fingerprint

示例：脑连接的指纹图谱

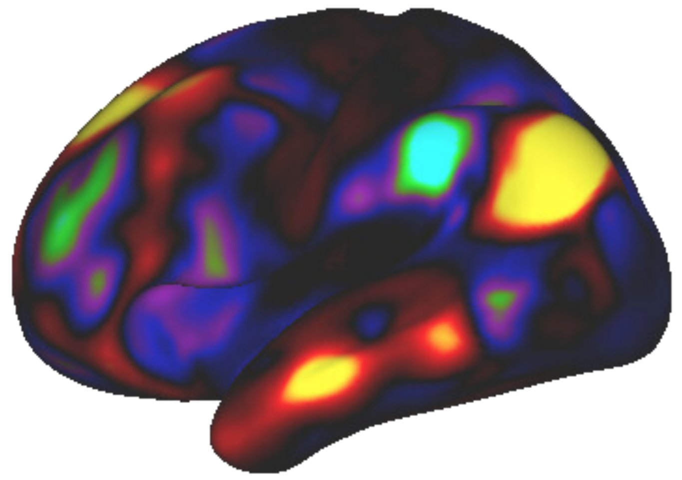


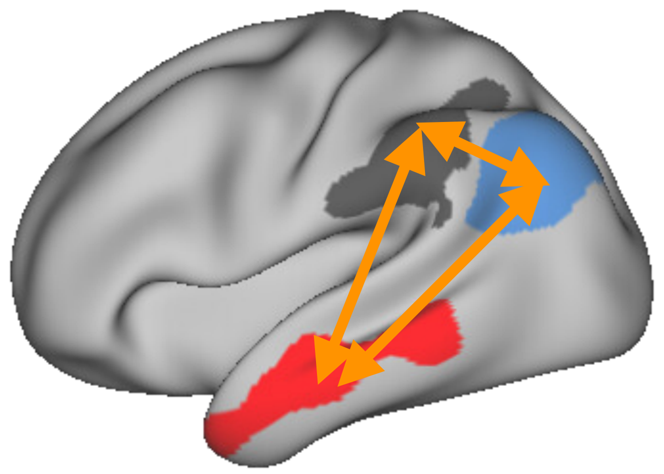


Finn et al (2015)

Comparison of methods
方法比较

Overview of resting state methods
静息态方法的概况





<u>Voxel-based 基于体素</u>

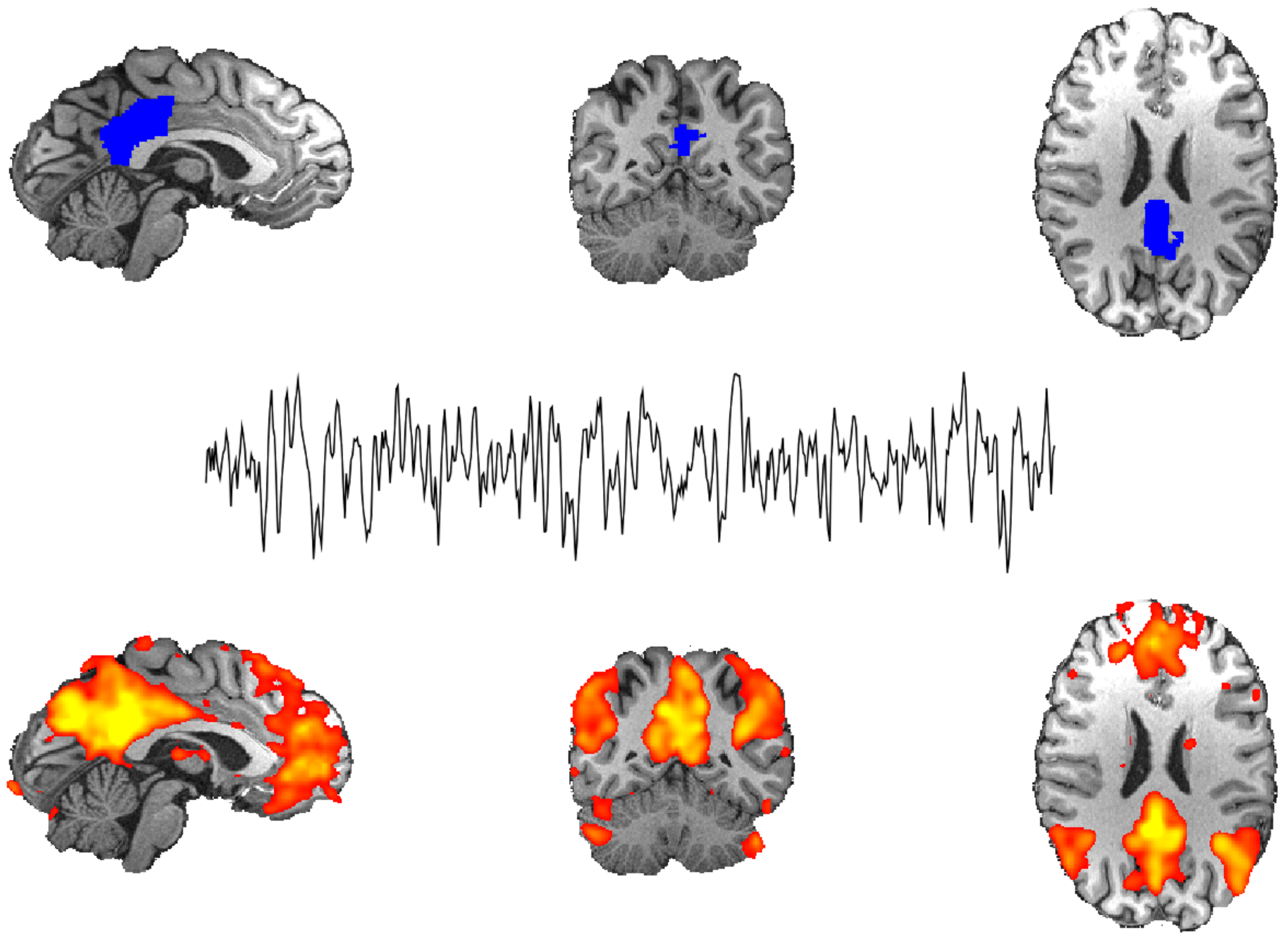
- Seed-based correlation analysis基于种子点的相关分析
- Independent component analysis独立成分分析
- Amplitude of low frequency fluctuations低频波动的幅度
- Regional homogeneity 局部一致性

<u>Node-based 基于节点</u>

- Network modelling analysis网络建模分析
- Graph theory analysis 图论分析
- Dynamic causal modelling 动态因果建模
- Non-stationary methods 非稳定的方法

Seed-based correlation
基于种子点的相关分析

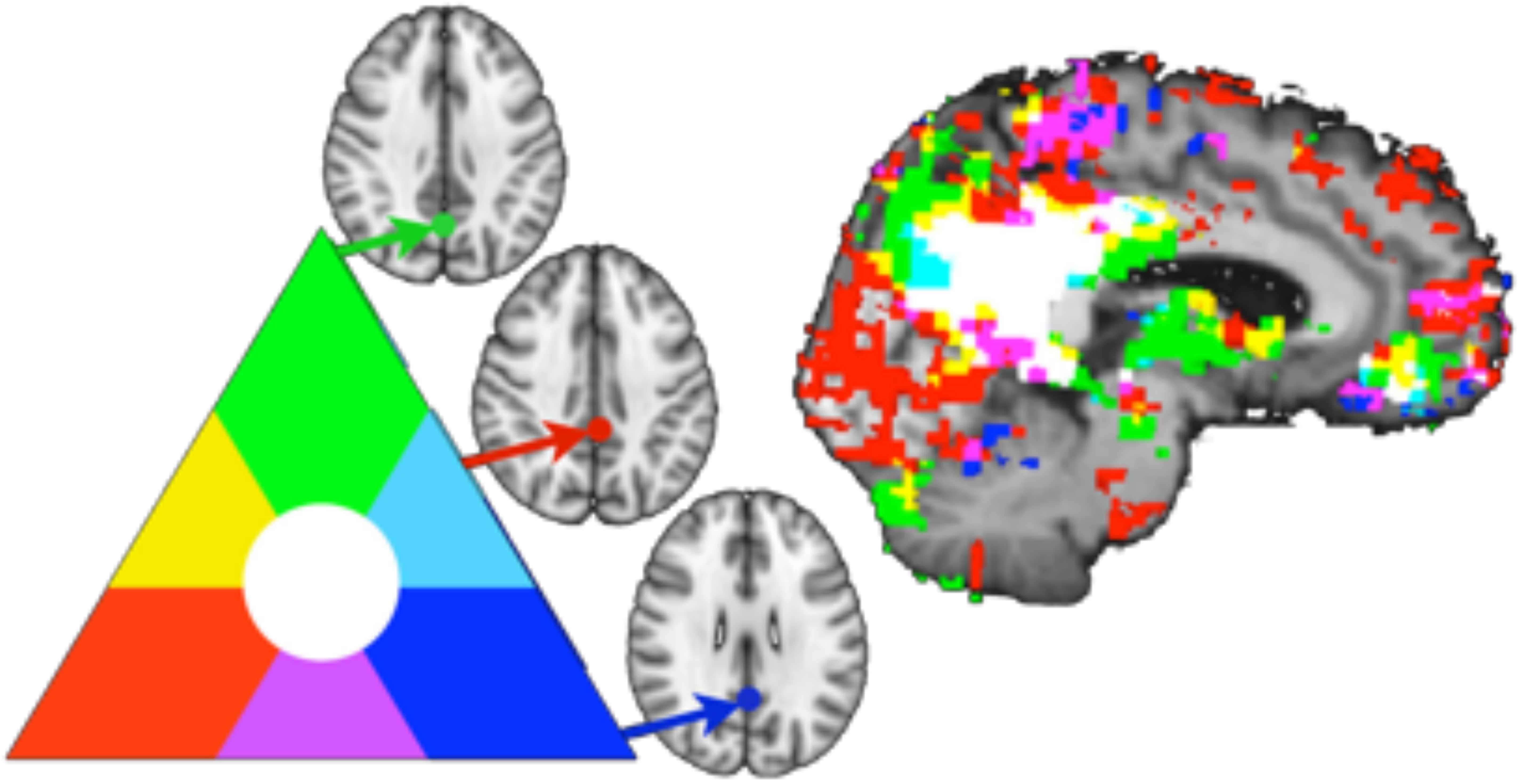
- Easy to interpret 易于解释
- No correspondence problem 没有一致性问题
- Seed-selection bias 种子点选择偏差
- Only models seed-effect (ignoring complex structure & noise) 只模拟种子点效应（忽略复杂的结构和噪音）



Seed-selection bias
种子点选择偏差

Seed-based correlation results are strongly influenced by small changes is seed location

基于种子的相关结果受种子位置的微小变化的强烈影响



Cole et al (2010)

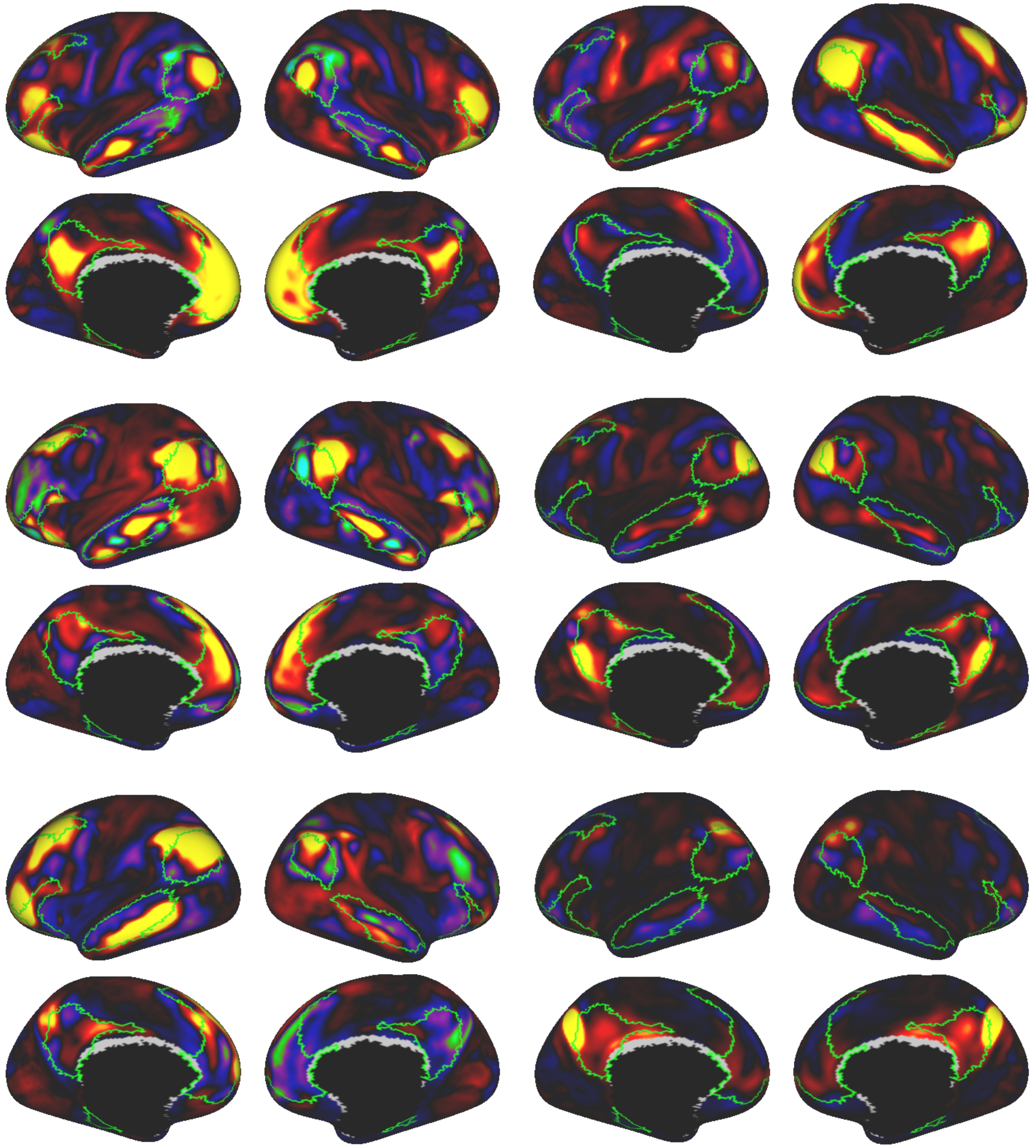
ICA
独立成分分析

- Multivariate: decompose full dataset
  多变量：完全分解数据集

- Test for shape & amplitude
  测试形状和振幅

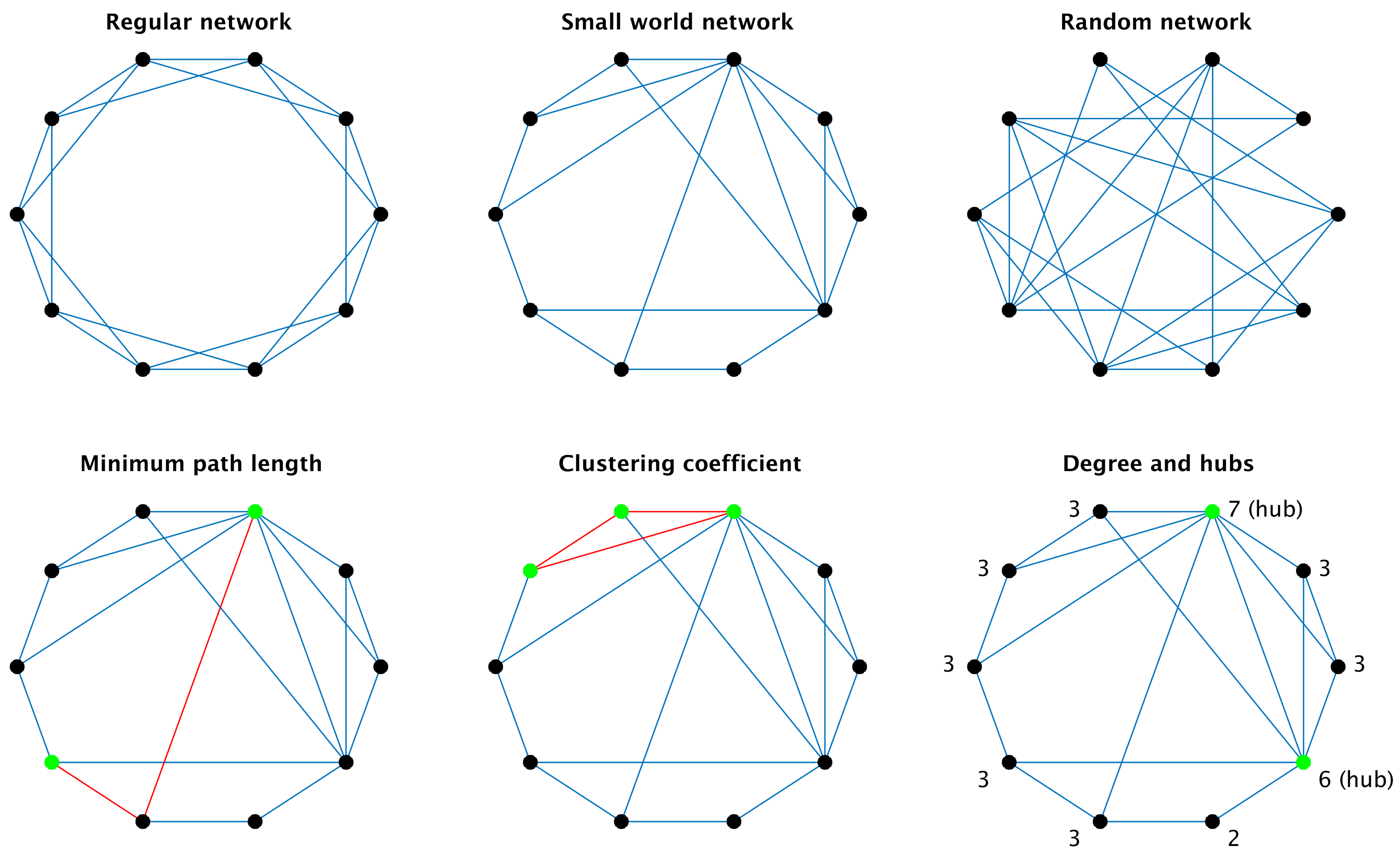
- Can be hard to interpret 可能难于解释

- No control over decomposition (may not get breakdown you want)
  成分无法分解（可能无法获得您想要的）



Graph theory
图论

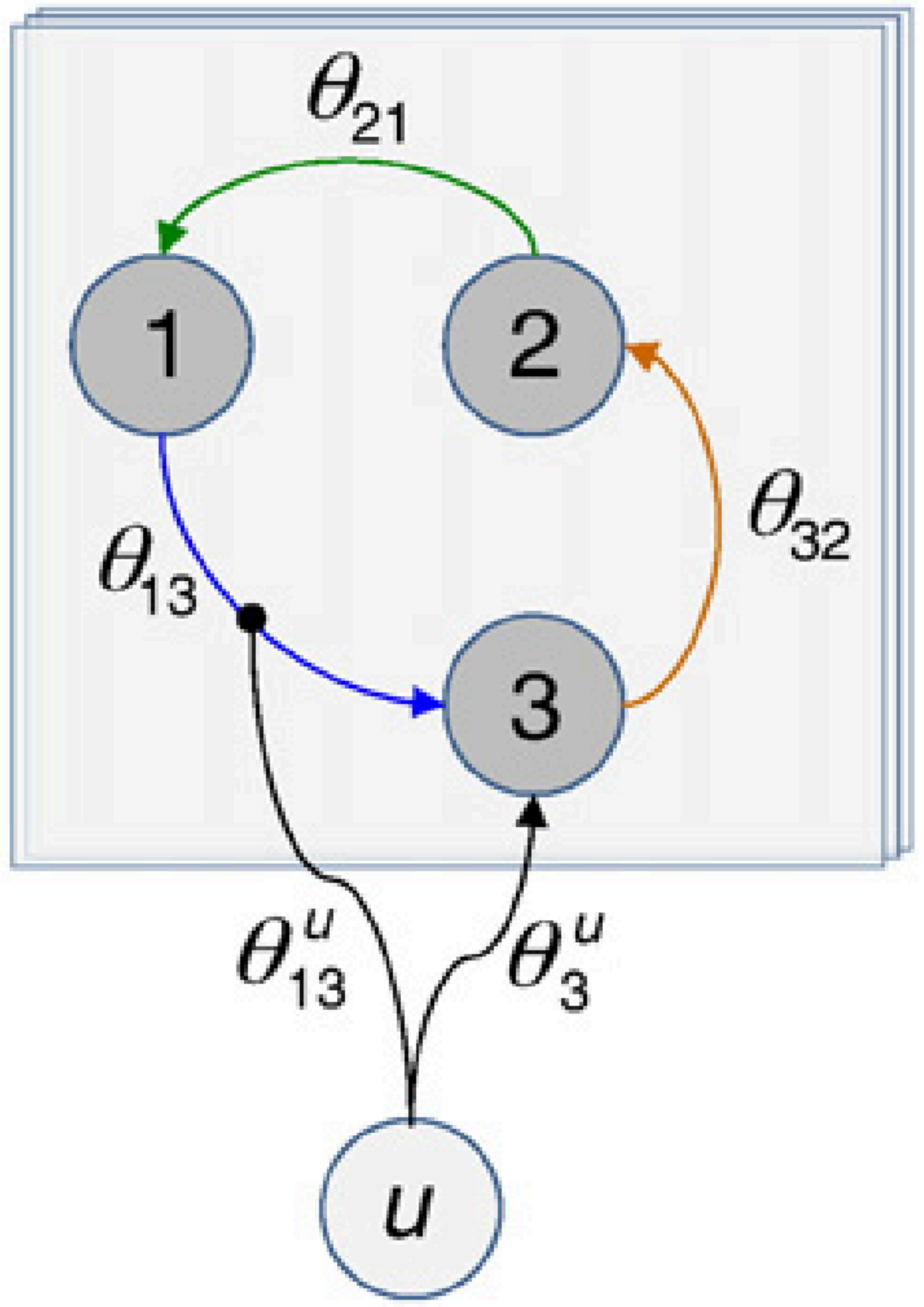
- Simple summary measures (derived from network matrix) 简单的汇总方法（源自网络矩阵）
- Network matrix often binarised 网络矩阵经常被二进制化
- Difficult to meaningfully interpret (abstract and far removed from data) 很难有意义地解释（抽象和远离数据）



Rubinov et al (2010)

Dynamic causal modelling
动态因果模型

- Directional interpretation (effective connectivity)
  定向解释（有效连接）
- Biophysical model 生物物理模型
- Assumes HRF homogeneity 假设HRF同质性
- Limited model comparisons 有限的模型比较



Daunizeau et al (2011)

Overview of node-based methods

基于节点的方法概述

graph theory 图论

clusters / hierarchies, network hubs,
network summary statistics (e.g. small-worldness, efficiency)

集群/层次结构，网络节点
网络统计方法 （小世界、有效性）

network modelling from FMRI data

FMRI数据的网络建模

functional connectivity
simpler, less meaningful,
network "discovery",
better conditioned,
can handle more nodes

功能连接
更简单，较少意义，
网络"发现"，
条件更好，
可以处理更多节点

- full correlation
- partial correlation
- regularised partial correlation
- Bayes nets
- SEM
- non-biological dynamic Bayes nets
- biophysical neural-groups to FMRI-signal forward model, fit to data using Bayes (e.g. DCM)

- 完全相关
- 偏相关
- 正则化的偏相关
- 贝叶斯网络
- 结构方程模型
- 非生物动态贝叶斯网
- 生物物理神经组到FMRI信号正向模型，适合使用贝叶斯（例如DCM）的数据

effective connectivity
more complex, more meaningful,
pre-specify (constrain) network model,
harder to estimate,
can handle fewer nodes

有效性连接
更复杂，更有意义，
预先设定（限制）网络模型，
更难预测模型，
可以处理较少节点

closeness to (interaction with) real FMRI data

bottom-up neural network simulations

network of individual neurons simulated

network of groups of neurons simulated (e.g. neural mass model)

由下至上的神经网络仿真
单个神经元组成的仿真网络

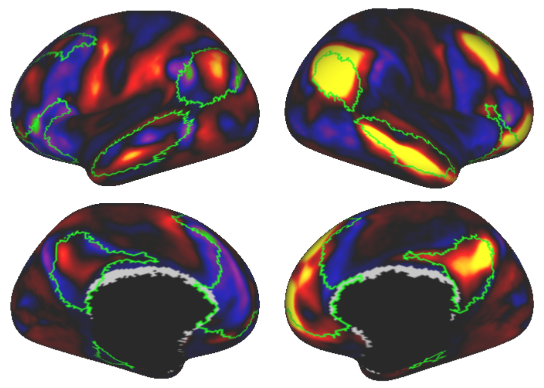
神经元簇组成的仿真网络
（例如神经团模型）

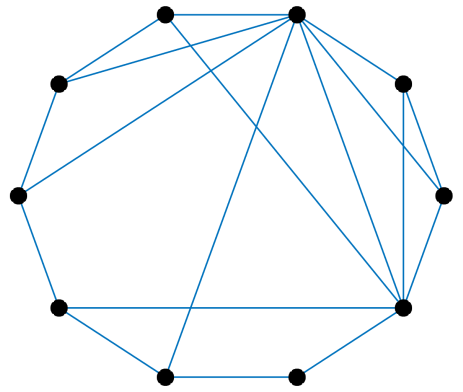
Which method to chose?

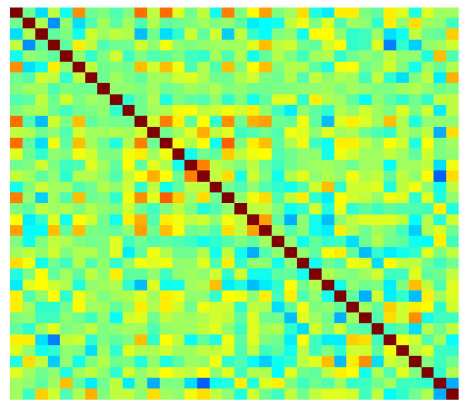
选择哪种方法?

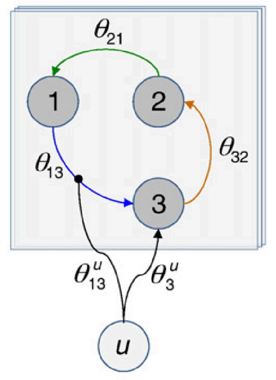
Interpretation 解释

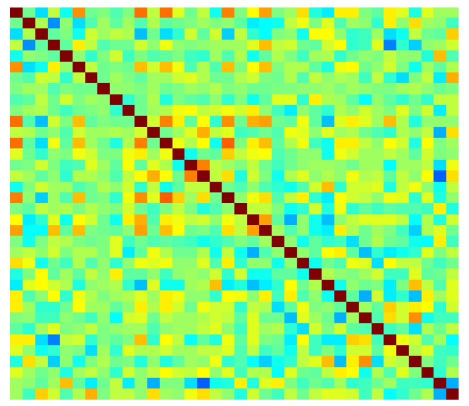
- **Relationship to RSNs** 与RSN的关系 → **Dual regression** 双回归
- **Summary values** 汇总 → **Graph theory** 图论
- **Connections in system** 系统连接 → **Network modelling** 网络建模
- **Biophysical system** 生物物理系统 → **DCM** 动态因果模型
- **Connectomics** 连接组学 → **Network modelling** 网络建模





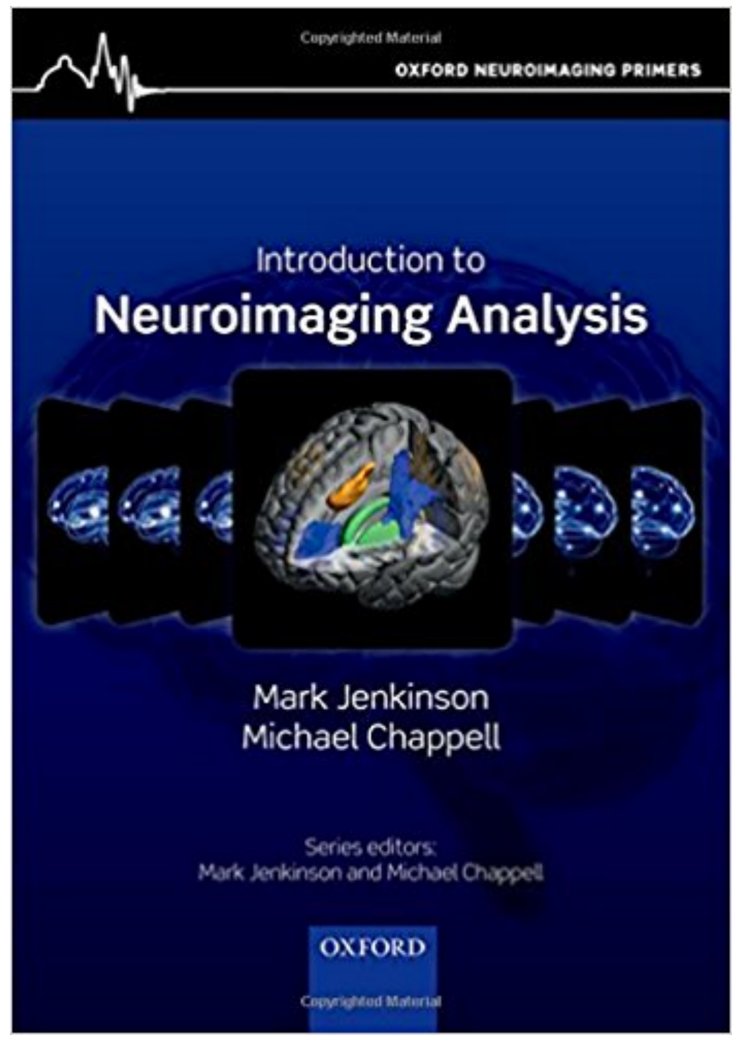


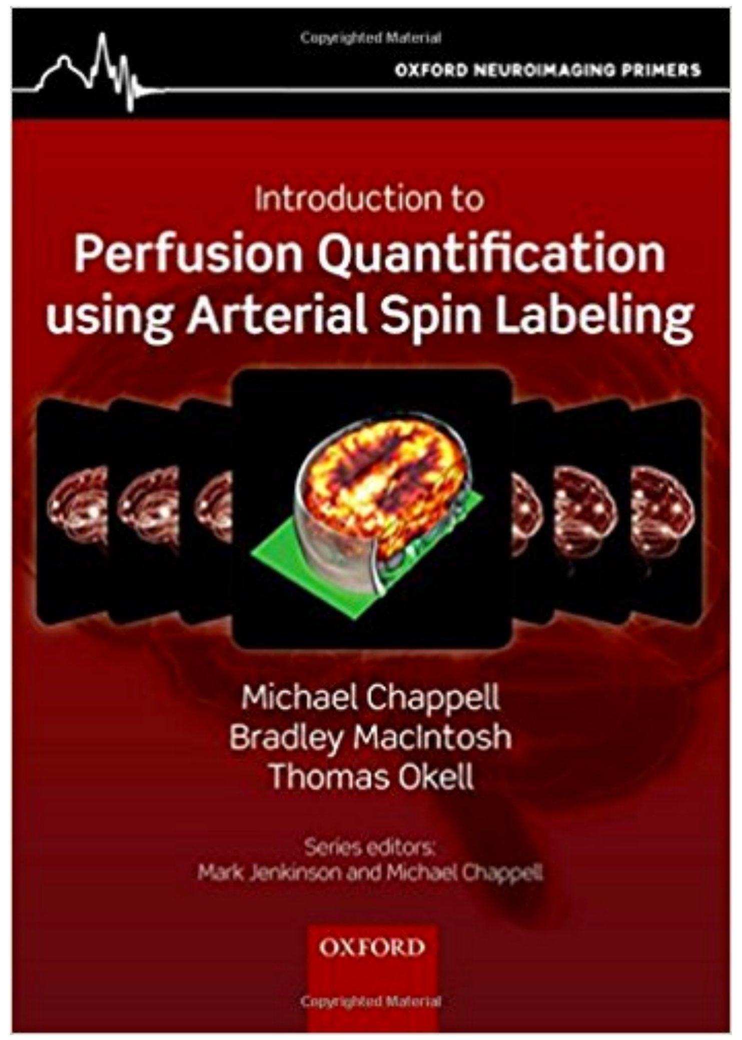




The book

- Part of a series of Oxford Neuroimaging Primers 一系列牛津神经影像引物的一部分
- Available from Amazon and Oxford University Press 可从亚马逊和牛津大学出版社获得
- Free material available on primer website: http://www.neuroimagingprimers.org/
- Please consider writing a book review on Amazon





That’s all folks